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# Importance and Prospects for the Development of Work in the Field of Solar Energy Using

This issue of the Light and Engineering Journal is devoted to important problem of the state and development of photovoltaic or solar energy using in Photo-Voltaic (PV) systems in China.

The task of expanding the scale of application and improving the technical and economic characteristics of renewable energy sources (primarily photo-wind power plants) is one of the most important in providing energy for modern human society.

Over the past decades, significant progress has been made in the creation and use of renewable energy sources. According to Professor O.S. Popel from Joint Institute for High Temperature of the Russian Academy of Science (JIHT RAS), the total installed capacity of such operating systems in the world reached 950 GW. At the same time, 40–45 % of this total installed capacity is accounted for by photovoltaic installations. In June 2017 at the World Economic Forum in St.-Petersburg in the report "Global Energy of the Future", the following projected figures for the use of solar energy in the global energy balance were named: 2018–7.4 %, 2035–18.8 %, 2100–25.5 %. Up to 20 % increased the efficiency of conversion of solar energy into electrical energy. The cost of photovoltaic panels has appreciably decreased and the parameters of storage batteries have improved (O.S. Popel, V.E. Fortov "Renewable Energy in the Modern World ", Tutorial, Moscow, MPEI Publishing House, 2015).

In a number of states, there are government programs to expand the use of renewable energy sources. For example, in Germany there is the program «Million solar roofs».

This problem, especially important for countries with low latitude territories and a large number of clear sunny days, is receiving much attention in China with result the country is one of the leading countries in the development and use of photovoltaic systems.

In the residential sector (single-family houses), the current use of such systems and installations in China allows to reduce the consumption of electricity from the centralized electricity supply by 15–20 % and to ensure the return on investment costs for 12–15 years. When creating large centralized photovoltaic stations, these indicators improve noticeably. In the near future, it is possible to forecast both a further significant increase in the use of photovoltaic systems, as well as an increase in their technical and economic indicators and a reduction in the payback period.

In this regional issue of the journal «Light and Engineering» a complex of problems of the creation of photovoltaic systems and their application in China in recent years is considered. Such organizational, legal, financial, personnel, logistics experiences, experience of implementation, and installation and operation, it is important to know and use in all countries that have territories with a large number of sunny days per year.

The editorial office invites experts from companies and organizations of different countries working in the photovoltaic field to take part in discussing existing problems and informing about achievements in this important and promising area in the pages of the "Light and Engineering" and "Svetotekhnika" Journals.

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СВЕТОТЕХНИКА



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Light & Engineering" is an international scientific Journal subscribed to by readers in many different countries. It is the English edition of the journal "Svetotekhnika" the oldest scientific publication in Russia, established in 1932.

Establishing the English edition "Light and Engineering" in 1993 allowed Russian illumination science to be presented the colleagues abroad. It attracted the attention of experts and a new generation of scientists from different countries to Russian domestic achievements in light and engineering science. It also introduced the results of international research and their industrial application on the Russian lighting market.

The scope of our publication is to present the most current results of fundamental research in the field of illumination science. This includes theoretical bases of light source development, physiological optics, lighting technology, photometry, colorimetry, radiometry and metrology, visual perception, health and hazard, energy efficiency, semiconductor sources of light and many others related directions. The journal also aims to cover the application illumination science in technology of light sources, lighting devices, lighting installations, control systems, standards, lighting art and design, and so on.

"Light & Engineering" is well known by its brand and design in the field of light and illumination. Each annual volume has four issues, with about 80–140 pages per issue. Each paper is reviewed by recognized world experts.

To promote the work of the Journal, the editorial staff is in active communication with Thomson Scientific (Citation index) and other international publishing houses and agencies, such as Elsevier and EBSCO Publishing.

# CONTENTS

VOLUME 25 NUMBER 3 2017

## LIGHT & ENGINEERING

*Light & Engineering*
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# THE CURRENT STATE OF DEVELOPMENT, PRODUCTION, AND USE OF THE PHOTOVOLTAIC SYSTEMS IN CHINA AND PERSPECTIVES OF THEIR EVOLUTION

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## ABSTRACT

Since entering the 21st Century, China's photovoltaic (PV) industry has been developing at very high speed. However, since the global economic growth becomes slower and the PV industry faces excess manufacturing capacity, both opportunities and challenges manifest for the Chinese PV industry. This paper summaries and analyzes the development, operations, and current status of PV technology applications, and reviews the prospects for future industry development toward providing references for relevant academic researchers, industrial practitioners, and policy makers.

***Keywords:*** China's photovoltaic industry, development, operation, application, current status, prospect

## 1. INTRODUCTION

Energy is a necessity for human development. At present, with the deterioration of supply and demand for energy, on the one hand, energy shortages have arisen; on the other hand, the energy industry must meet environmental challenges [1]. Both comprise the core of global 21st century energy issues. The current consensus of the energy industry is to seek fungible and clean energy, of which solar energy is one of the most pollution-free and advantageous forms of energy in the world [2]. In the 21st century, with the global economic growth becoming slower [3] and the energy industry facing excess manufacturing capacity, both opportunities and challenges have manifested for China's photovoltaic (PV) industry. The "Manufacturing in China 2025 Strategy" indicates that the domestic manufacturing industry has great scale, Fig.1, but it is not sufficiently strong enough to meet certain challenges [4]. In the face of bi-directional compression from both, developed and developing countries, how to change its development mode to position it in the context of global production and to achieve sustainable development comprise the current challenges of the PV industry in China. Therefore, from the aspects of development, production, and application, in this paper we analyze on Chinese PV industry and predict the course of its future development with the aim of providing references for relevant academic researchers, industrial practitioners, and policy makers.

## 2. CURRENT DEVELOPMENT STATUS OF CHINA'S PV INDUSTRY

### 2.1. Trend of vertical integration in China's PV industry

China's PV industry consists of three parts: the upstream, midstream, and downstream parts. The upstream part includes purification of polycrystalline silicon and silicon wafer casting and slicing. The midstream part includes battery assembly and component production. The downstream part includes the construction and operation of PV grid-connected plants and off-grid distributed power stations [5].


Fig.1. China's photovoltaic (PV) industry has been developing at very high speed

### 2.2. Improvement of industry scale and competitiveness

China has been engaged in the development of solar batteries since 1958. In 2014, the production of photovoltaic batteries in China contributes 73.33 % to the global market. China's PV industry is growing against the global trend. Solar battery and component production has expanded the export scale to diverse markets, and China's PV industry has greatly improved its market competitiveness and global market standing.

### 2.3. Expansion of PV market with diverse applications

Since 2015, China's PV market has grown continuously. The newly installed capacity has exceeded 15 GW with a year-on-year growth of 41.5 %, which ranks first globally. China's cumulative installed capacity has exceeded 43 GW, which has led to China overtaking Germany to become the country with the largest cumulative PV installed capacity in the world. Meanwhile, the applications of PV techniques have become much more diverse. Although large ground power stations still comprise 80 % of the overall installed PV capacity in China, the development of PV applications has emerged in various industries, including agriculture, aquaculture, mining, and ecological control. Stimulated by the relevant government policies, the scale of distributed PV power stations has significantly increased. New PV power stations are mainly located in the middle eastern China, where the electricity demand is higher and much more concentrated. Many new PV products have also become available, such as PV pumps, PV trees, and PV lamps.

### 2.4. Lack of urgently needed core technologies and technology innovations

The core techniques of the PV industry have generally been monopolized by just a few developed countries, such as the U.S., Japan, and Germany. For extraction of polysilicon, China's PV industry still uses the inferior modified Siemens method, by which the electricity consumption for producing one solar battery unit is between 3 and 5 units, which is very high and uncompetitive. Meanwhile, China lacks polysilicon recycling technology, which has resulted in both the inefficient usage of polysilicon and environmental contamination [6].

### 2.5. High industry integration costs, difficulties in regulating industry norms

The proposal of "Solar PV Industry Access Conditions" has been completed by the Ministry of Industry and Information Technology of the People's Republic of China. This proposal specifically regulates the scale of production, research and development (R&D) capability, and transfer efficiency of enterprises. However, there are still many noncompliant enterprises entering the PV industry, which violates the conditions of the proposal. Therefore, huge difficulties in regulating China's PV industry still exist [7–8].

## 3. CURRENT OPERATIONAL STATUS OF CHINA'S PV INDUSTRY

After the onset of the 21st century, although China's PV industry has experienced rapid development and made remarkable achievements, many problems exist. The problems from an operational perspective are detailed in the following subsections.

### 3.1. Excess of production requiring structural adjustment

Up to now, most PV enterprises have focused on expanding or initiating new PV projects. Along the length of the entire industrial chain of crystalline silicon, silicon slicing, solar battery production, and battery component and system installation, the problem has become more severe the lower stream a particular enterprise is engaged in. Meanwhile, the lack of high-end products cannot satisfy the needs of a high-end market, which affects the efficacy of sustainable industrial adjustments and industry layout [2].

### 3.2. Limited R&D and innovation capability

Owing to the fact that the core technologies mainly depend on their introduction in China from non-domestic sources, and the lack of outstanding R&D capabilities of a high-end technical workforce, China's PV industry manufactures more low-end products and fewer high-end products. Simultaneously, China's institutional background has suppressed the innovations of local scientific researchers.

### 3.3. Financing impediments to PV industry development

The PV industry is a high-tech industry as well as a capital-intensive industry. At the beginning of the 21st century, China's PV industry raised funds through the capital market and achieved remarkable growth in a short timeframe. However, now there are many problems in the financing channels of China's PV industry: first, equity financing is blocked; second, bank financing is restricted; third, bond financing is frozen [5].

### 3.4. Inversion phenomenon of industry and markets

In recent years, for the rapid development of China's solar PV industry, China has become the world's largest solar cell producer. Compared to China's huge solar battery production capacity, China's solar energy demand is relatively small. China's current solar battery production is mainly for export. Compared to foreign demand, the domestic demand is seriously insufficient. Hence, China's PV industry is a typical export-oriented industry. Raw materials and the market are mainly located in foreign countries. This inversion phenomenon of both industry and markets is still a serious issue [9].

### 3.5. PV power generation cost needs to be reduced

The main reason for the delayed growth of China's photovoltaic market is that the cost of PV power generation is still too high, which affects the industry's large-scale expansion. At present, the cost of China's PV power generation ranges from 1.3 yuan/degree to 2.0 yuan/degree, which is much higher than the cost of coal-fired power, the average cost of which is less than 0.30 yuan/degree. Such a high cost has long been a bottleneck in the development of the PV industry in China and the world. The cost of solar cells in the entire photovoltaic power generation system is in the highest proportion, comprising more than 60 %, and the largest part of the cost of solar cells, polysilicon materials, accounts for over 50 % of the total.

The improvements in preparation technology and cell conversion efficiency, lower raw materials procurement costs, and encouraging govern-

ment policies will greatly reduce the cost of solar power generation. It is expected that the cost of solar power generation will be closer to the non-solar-produced electricity cost in the next five to ten years [10].

## 4. CURRENT STATUS OF CHINA'S PV APPLICATION ENVIRONMENTS

### 4.1. Sustaining improvement of application environments

Technology progress is an important cornerstone in the development of China's PV applications. At present, to further promote the demand for high-efficiency monocrystalline PV applications, including the demands of CSG, IRSTS, and MPPT, China has consistently promoted relevant expertise levels. With the continuous development of the single-crystal continuous feeding process and of G7 and G8 large-capacity casting technology, King Kong line-cutting technology will be further employed, which will lead to increased scales of production. This situation pushes enterprises to make progress through technology improvement and product differentiation. In addition, through automation intellectualization and flexibility, the PV industry will achieve transformation from "Manufacture" to "Manufacture with Wisdom".

### 4.2. Expanding the range of applications

Although problems such as electricity price decreases, great variation in land taxes, and subsidy defaults still exist in China's PV industry, the government still implements policies such as deregulation to ameliorate the difficulties. Influenced by national policies, the scale of PV generation has expanded that broadens the scale of its application and emphasizes the Middle Eastern region of the country which needs more electricity.

### 4.3. PV power has a low share of the national energy mix

Coal is in the dominant source in China's energy mix. From the time of reforms to the present, coal has accounted for more than 70 % of China's total energy production, followed by crude oil and natural gas. Although China has increased its investment in new energy sources during the 10$^{th}$ Five-Year Plan and the 11$^{th}$ Five-Year Plan, the new energy share has not increased obviously in terms of energy infrastructure. In 2010, new energy accounted for 9.4 % of total energy production, an increase of only 1.5 % compared to that in 2000. The entire new energy mix is low, and PV production contributes a lower proportion to overall new energy production. China's annual capacity is close to 5 trillion kW, while solar PV capacity is less than 100 MW, and PV power generation accounts for less than approximately 1 % of the total capacity [11].

### 4.4. Small proportion of distributed PV power stations

Compared to the countries more advanced in PV applications, China's PV installation scale is smaller, and the infrastructure for PV applications is also different. Theoretically, although solar radiation constitutes a huge energy source, the amount of light heat received per unit area is relatively small. Therefore, the best approach to solar energy utilization in China should be "scattered, local consumption". Most countries focus more on the construction of decentralized power plants in the development of a solar PV power generation market. Compared to other countries, China's rooftop photovoltaic power plant development has been very slow, and the supporting policies have also been focused on developing large-scale photovoltaic power stations. By the end of 2011, the government has supported the construction of large-scale power stations as a target of the "Golden Sun Demonstration Project", the third phase of which approved a total output of 1.2 million kW, which is 4 times more that approved for the development and utilization of the "Solar Roof Plan", Fig.2, which aimed at a total capacity of 300000 kW. However, this kind of "large-scale, high-concentration, long-distance, high-voltage transmission" development model has significant limitations. The western region of China, which is abundant in land resources and solar energy resources, has no shortage of electricity. However, the light conditions of the eastern region, which has tension of the domestic power supply, are poorer than those of the western region, and, moreover, it has a shortage of land resources. If the western region develops large-scale PV power plants, it will face the problem of long-distance transmission. Owing to the high cost of PV power generation, the economic benefits will become

Fig.2. Construction of large-scale power stations

very low if coupled with thousands of kilometres of transmission costs.

## 5. PERSPECTIVES ON CHINA'S PV INDUSTRY

### 5.1. Industrial development intellectualization

Industrial development intellectualization mainly focuses on two perspectives. First, the current attention paid to intellectualization has aroused the attention of the PV industry and led to industrial expansion. The long-term power generation stability of PV power plants, component quality, and follow-up maintenance has a significant inter-relationship. Therefore, PV enterprises must be proactive to evade risks caused by equipment failure by leveraging attention intellectualization in order to maximize enterprise benefits. Second, due to the high demands of domestic and foreign PV markets, a single product is unable to meet market demands. Diversified and intellectualized products are conducive to application and installation, and accordingly to realize the energy internet.

### 5.2. Increasing the number of financing channels

The difficulties caused by sparse financing channels and high financing costs must be resolved. The support of industrial policy and the stability of PV enterprises are the basis of refinancing. Financing methods must be conducive to widening financing channels, reducing financing costs, and increasing the benefits derived from investments, including financing leases, internet financing, crowd funding, and trust and asset securitization.

### 5.3. Acceleration of industrial infrastructure upgrades

At present, the development of China's PV industry has neglected the service market of PV power stations, such as quality rating services and power station insurance services. A quality rating service rates the quality of a PV power plant by evaluating the site's location, system performance, equipment quality, installation quality, and other dimensions. Such a service's effective and true rating

can enhance investor confidence, and further promote industrial development. Power station insurance services provide guarantees for natural risks and manmade accidents, and can also help plan for avoiding industry-specific risks.

### 5.4. Heightened "anti-dumping and anti-bribery" awareness

Since "anti-dumping and anti-bribery" awareness has been heightened, the foreign market will further tighten. The PV industry depends on external market development. Before 2011, the degree to which China's PV industry depended on external markets had reached 90 %. Since the industry's overall capacity continues to surge, the international competition between industries has become fiercer. From the beginning of 2009, China's photovoltaic industry has been faced with the threat of "anti-dumping subsidies" many times. In November 2011, the U.S. started an "anti-dumping and anti-bribery" investigation of China's PV industry. The final result of the investigation was to levy an "anti-dumping tax rate of 18.32–249.96 %, 18.32–15.97 % of the subsidies tax rate" on China's PV industry. The European Union also conducted an "anti-dumping and anti-bribery" investigation in China. For the stricter European and American markets, China's PV industry should respond as follows: first, actively explore new international markets, such as southern Africa, where the electric power supply is relatively underdeveloped; second, to transfer part of the labour-intensive industry sections to Southeast Asia, South America, and other regions to avoid the restriction imposed by "double against"; third, push the government to take actions to defend against such "anti-dumping and anti-bribery" investigations to avoid "effect of wolves" in the case of a worsening external market environment [5].

## 6. TIME PERIOD OF INVESTMENTS PAY OFF

Different photovoltaic power generation projects have different investment cycles, mainly including the following three types:

– Investment cycle of family distributed power station project requires the higher conversion efficiency and quality of components, which results in higher input costs. At present, the amount of investment is higher in the initial stage of construction, the smaller of the dimension and the lower of the construction cost. At the same time, the cost of residential electricity is much lower than that of industrial electricity, which makes the recovery of family distributed power station more difficult. Therefore, the development of distributed photovoltaic is constrained by cost problem, which affects its investment income. The results of family distributed investment for photovoltaic system in July 2015 (the peak period of electricity consumption) are shown as an example in Table 1. Although the family distributed power station is energy savings and environmental protecting, its years of cost recovery is very long and the cost of one-time investment is very high. In the latter construction, this type of photovoltaic power generation project requires technical innovation and the batch installation to reduce system installation, operation cost and improve the capacity [12].

– The operating mode of landing power station is more flexible than the distributed power station, so its recovery cycle is shorter and the benefit is greater than at the latter. For example, a 50 MW photovoltaic project of the energy-saving is established by China Energy Conservation and Environmental Protection Group and Shangde Solar power in Wuxi. This project plans to build 50 MW solar photovoltaic power generation with a total investment of 2.5 billion. The investment of the first phase of 10 MW solar photovoltaic power generation project is about 250 million, which installed with more than 37,000 polysilicon panels and 15260 brackets. This project is established in October 1, 2010 and achieves grid-connected electricity generation. The online price of the electricity is 1.15 yuan/kWh and its investment recovery period is 8 to 10 years. The project can earn from three aspects: First, it needs to invest 40 % to provide all of the components. Then it can get profit by selling components. Second, according to the electricity price of 1.15 yuan/kWh to calculate, it can also get part of the income from the power plant. Third, the constructor of this project is the installation company of Shangde Solar power [13].

– Investment cycle of the energy performance contracting project, or through signing the contract of energy-saving services with customers, the energy-saving company is solely responsible for the initial investment of the project and owns the state subsidy to make the owners of the initial zero in-

**Table1. Example of family photovoltaic system budget and investments pay off**

| Installation cost (yuan) | Scale (W) | Network time (Month) | Power Generation (kWH) | Electricity/ month (yuan) | Subsidy/ month (yuan) | Profit/ month (yuan) | Profit/ year (yuan) | Years of cost recovery |
|---|---|---|---|---|---|---|---|---|
| 84000 | 8400 | 10 | 4596 | 270.97 | 193.03 | 464 | 5568 | 15 |

vestment to improve their motivation. After the project application is in place and the construction is completed, the energy conservation company charges a monthly fee according to the contract. At the same time, both sides can agree that the photovoltaic power station will be transferred to the owner after several years. According to the lease time of 15 years, energy-saving company can recover all the investment in 4.6 years and the net operation profit in the remaining years can achieve about 1.65 million [13].

## 7. CONCLUSIONS

From the aspects of development, production, and application, we draw the following conclusions from the analysis of China's PV industry presented in this paper:

– Current state of development: There is a trend of vertical integration in China's PV industry. The industrial chain of China's PV industry consists of three parts, and the industry scale is increasing rapidly and industry competitiveness is becoming fiercer. In addition, the development of China's PV market has diversified.

– Current state of production: Adjustments to infrastructure are urgently needed to solve the problem of excess capacity. R&D and innovation capabilities are insufficient, and a new and effective mechanism of cultivating high-tech researchers is needed. Financing difficulties impede industry development, and the government should implement effective supporting policies.

– Current state of applications: There are sustaining promotions of conditions and an expanding range of applications in China's PV industry, which has accomplished a transformation from "Manufacture" to "Manufacture with Intelligence".

– Perspectives on Chinese PV system evolution: Industrial development intellectualization can be accomplished through production intellectualization, channel diversification, and lower financial costs. Such intellectualization can also solve financing problems and can emphasize the use of market services to accelerate the speed of PV industry evolution.

– The residential electricity consumption decreases in an average of 15 % when the photovoltaic cells are putting into operation in a house [14].

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# A STUDY OF THE INFLUENCING FACTORS OF THE TECHNOLOGICAL INNOVATION IN PHOTOVOLTAIC ENTERPRISES

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## ABSTRACT

With the rapid development of economy in the era of knowledge economy, an increasing conflict breaks out among economy, resources and environment. Therefore, wide attention is drawn to renewable resources and new energy enterprises, especially photovoltaic (PV) enterprises. After analysis of the status quo of PV technology and the key factors of technological innovation of PV enterprises by means of literature research, questionnaire survey and statistical analysis, this thesis lists the core problems of technological innovation of PV enterprises, which can provide a theoretical basis for PV enterprises to make greater contributions to the harmonious development of economy, energy and environment.

***Keywords:*** knowledge economy, renewable resources, photovoltaic enterprises, technological innovation, influencing factors

## 1. INTRODUCTION

In the era of knowledge economy, technological innovation is a key driver of economic development and social progress. Throughout the world, countries, especially developed countries, pay much attention to technological innovation to improve their comprehensive national strength including economic strength [1]. In the context of high-speed economic development featuring increasingly fierce market competition, if any industry or any business wants to develop, they must have their own competitive advantage including cost advantages, service advantages, quality advantages, talent advantages which are inseparable from the continuous technological innovation [2].

Renewable resources can alleviate the conflict among the current economic development, resources and environmental development. The development and utilization of new energy has become a public concern in the hope that it will become a new engine of economic growth [3]. The Chinese government strongly supports the development and utilization of new energy and makes the new energy industry one of the seven strategic emerging industries. Within the new energy industry, China's PV industry is developing rapidly with a huge scale. There are already 500 plus PV enterprises enjoying a big global market share, 20 of which are listed companies. China is also among the top ten manufacturing countries [4].

## 2. STATE OF THE ART

Solar energy, a key part in the development and utilization of renewable resources, is featured with abundance, high availability, and free of pollutions [5]. Developing and utilizing solar energy resources not only brings economic benefits but also effectively alleviate the pressure of energy consumption and environmental destruction. At present, solar thermal industry and solar photovoltaic industry serve as two main ways for developing and utilizing new energy [6].

Supporting the development of new energy industry, especially the development of photovoltaic industry, is an important way to optimize China's energy structure, ease the uncoordinated development of the above-mentioned three aspects and achieve energy saving and emission reduction. China's solar photovoltaic industry, started in 1970s, has a history of more than 40 years. At present, there are more than 500 professional Chinese photovoltaic companies. In recent years, China is growing at a rapid rate of 200 % [7]. China has become the world's largest producer of solar cells, exceeding Europe and Japan in solar cell production with an output close to 1/3 of the world's total. In China, crystalline silicon cells are a major factor in the photovoltaic industrial chain. Despite its rapid development speed and large scale, there are still many problems in China's PV industry, such as the lack of core technology, weak policy support and technological innovation, uneven output and domestic market demand, poor innovation performance and inadequate current research on this series of problems [8]. At present, the increasing domestic production of crystalline silicon cells is far more than the market demand, leading to an oversupply situation. So, it is urgent to expand both domestic and international market [9]. However, market expansion is closely related with technological innovation as it can reduce production cost and improve production technology.

China's production of crystalline silicon cells has a big proportion in the world total and China's crystal silicon battery technology is able to keep up with the world advanced level. However, there is still a big gap in the level of technology between the PV industry and the world level due to China's relatively weakness in the key production technology for polysilicon and its high production cost. China's advanced equipment used in production is poorly developed, and it is mainly dependent on imports [10]. Therefore, China needs to pay more attention to technological innovation, reduce production costs, improve the efficiency of solar cells, optimize the production process, increase the intensity of high-end equipment R&D and gradually get rid of dependence on foreign imports to achieve the sustainable development of photovoltaic industry with strong competitiveness in the international market.

The main factors influencing the technological innovation are: the spirit of innovation (JS), corporate culture (WH), property rights incentive (JL), government policy (ZC), market structure (JG) and technological innovation willingness (YY). The development of photovoltaic industry and technological innovation optimization has attracted attention from some domestic academic experts who have conducted preliminary studies and discussions, such as Zhao Yuwen and other experts, who published the series of China PV industry annual reports. These reports summarized the current development status of the domestic photovoltaic industry, discussed the problems existing in the current development process, and put forward a lot of practical and valuable views and suggestions [11], but failed to do in-depth analysis of the basic methods to solve the problem and of the imbalance between production and market demand, to give professional suggestions on boosting technological innovation among the photovoltaic industry and point out major factors that affect their innovation and other professional issues. In a word, the technological innovation of China's PV industry has not been provided with professional data and analysis [12]. Therefore, this thesis analyzes the status quo of technological innovation faced by China's photovoltaic industry, the main factors influencing the technological innovation and explores ways to effectively improve the innovation performance, which lays a theoretical basis for the technological innovation of China's photovoltaic industry.

## 3. METHODOLOGY

Despite its rapid development speed and large scale, there are still many problems in China's PV industry, such as the lack of core technology, weak policy support and technological innovation, uneven output and domestic market demand and poor innovation performance [13]. In order to systematically study the main influencing factors of technological innovation in PV industry, this paper analyzes the close relationship between PV technological innovation and market development. After intensive literature review, this thesis consulted experts and related personnel, obtained a lot of relevant data from a large number of questionnaires, analyzed and summarized all the data by SPSS software. The effective analysis results were obtained, and the main factors that affect the technological innovation of photovoltaic enterprises were scientifically and systematically verified.

**Table.1. Main investigators in this study**

| Crowd | The number of people | Male to female ratio |
|---|---|---|
| Part of the photovoltaic company leadership | 20 | 4:1 |
| Part of the photovoltaic enterprise managerial staff | 30 | 3:2 |
| Part of the photovoltaic enterprise research and development and production staff | 120 | 3:2 |
| Photovoltaic enterprise phase light government department staff | 20 | 1:1 |
| Academic experts on photovoltaic industry | 10 | 3:2 |
| Total | 200 | 7:4 |

### 3.1. Literature review

This study reviewed a large number of Chinese and foreign literatures, analyzed and summarized the development situation and the problems of photovoltaic enterprises as well as the main technical innovation of domestic and international photovoltaic enterprises, which provides a valuable theoretical basis for the study of this paper and defines the research direction [14].

### 3.2. Questionnaire

In order to obtain a comprehensive and new data, this study used the questionnaire survey method. The survey was targeted for domestic professional PV business leaders and staff, and consulted and interviewed professionals, as shown in Tables 1,2. There were three main ways of investigation in the form of questionnaire, namely directly investigating the leaders of certain domestic photovoltaic enterprises and the staff in different positions, investigating the various photovoltaic enterprises which participate in the exhibition and consulting and investigating the various government departments related to PV enterprises, in order to understand government policy and support for the photovoltaic business in various regions [15]. Through the questionnaire survey using the above three kinds of methods, a lot of research data and the latest technological innovation information were obtained, which provided reliable data for the analysis and determination of the factors influencing the technological innovation.

### 3.3. Statistical analysis

In this study, a large amount of data was obtained through literature review, questionnaire survey and expert consultation. Finally, SPSS method was used to analyze and summarize a large amount of data. There are two aspects of data analysis: variance analysis and descriptive analysis. Intuitive and reliable results were obtained. The main influencing factors of technological innovation in PV enterprises were determined, providing scientific theoretical guarantee for the research of this thesis.

## 4. RESULT ANALYSIS AND DISCUSSION

### 4.1. Data analysis of the questionnaire

A total of 200 questionnaires were distributed in the survey, of which 12 were invalid due to incomplete and ineffective questionnaires and 188 questionnaires were valid. The data of the 188 questionnaires were analyzed by SPSS software to test the reliability and validity of the samples and to carry out multiple regression analysis of the data. The reliability analysis used the Cronbach's coefficient detection method. The criterion is that a coefficient between 0.9–0.8 represents the data very well, 0.8–0.7 indicates a good the data is better, 0.7–0.6 is still regarded as credible and 0.6 and below is considered untrustworthy. The results of the data analysis of this study are shown in Table 3. The values of each variable are 0.942, 0.9363, 0.907, 0.941, 0.945, 0.921 and 0.943 respectively, which indicates that the data is highly reliable. The validity of the questionnaire was measured by KMO. When

**Table.2. Content of the Questionnaire**

| Variable | Questions | Not conform | Not conform | A little coincidence | More accord | Very consistent |
|---|---|---|---|---|---|---|
| Corporate culture | WH1 companies continue to emphasize a belief that the courage to go beyond, strive for perfection | 1 | 2 | 3 | 4 | 5 |
| | WH2 companies encourage employees to learn in practice and apply their knowledge | 1 | 2 | 3 | 4 | 5 |
| | WH3 companies find and recognize innovation advanced individuals, teams, and timely dissemination of their deeds | 1 | 2 | 3 | 4 | 5 |
| Innovative spirit | JS1 business leaders often have new ideas to try | 1 | 2 | 3 | 4 | 5 |
| | JS2 business leaders can respect different opinions and objections | 1 | 2 | 3 | 4 | 5 |
| | JS3 business leaders encourage employees to try new processes, develop new products, and take a tolerant attitude towards failure caused by innovation | 1 | 2 | 3 | 4 | 5 |
| Property incentive | JL1's distribution system is fair, and it will reuse and promote a number of innovative and enterprising staff | 1 | 2 | 3 | 4 | 5 |
| | JL2 company established unified intellectual property management agencies to clear responsibilities | 1 | 2 | 3 | 4 | 5 |
| | JL3 government strengthened the industrialization of intellectual property support | 1 | 2 | 3 | 4 | 5 |
| Market structure | JG1 company has a large number of competitors in the industry and has a strong substitutability | 1 | 2 | 3 | 4 | 5 |
| | JG2 enterprises in which the industry's entry threshold is low | 1 | 2 | 3 | 4 | 5 |
| | JG3 enterprises in which the industry's competition continues to strengthen and intense, rather than weakened | 1 | 2 | 3 | 4 | 5 |
| Government policy | ZC1 local government supported the development of the industry and has developed support policies such as expanding the government's order to PV companies | 1 | 2 | 3 | 4 | 5 |
| | ZC2 enterprises can enjoy some tax relief, financial subsidies and other preferential policies | 1 | 2 | 3 | 4 | 5 |
| | The ZC3 government has developed a corresponding lending policy to support the enterprise | 1 | 2 | 3 | 4 | 5 |
| Innovation willingness | YY1 company emphasizes the initiative in the market competition | 1 | 2 | 3 | 4 | 5 |
| | YY2 is a leading company in the industry, which is very important to the company | 1 | 2 | 3 | 4 | 5 |
| | YY3 is more important to launch new products or services | 1 | 2 | 3 | 4 | 5 |

| Variable | Questions | Not conform | Not conform | A little coincidence | More accord | Very consistent |
|---|---|---|---|---|---|---|
| Innovation performance | JX1 new product sales accounted for a higher proportion of total sales | 1 | 2 | 3 | 4 | 5 |
| | JX2 in recent years has a high level of patent and new product profitability | 1 | 2 | 3 | 4 | 5 |
| | JX3 company has a greater proportion of invention patents | 1 | 2 | 3 | 4 | 5 |

the KMO value is higher than 0.7, the data can be analyzed by factor analysis. Through calculation and analysis, the KMO values of each variable in this study are 0.726, 0.761, 0.752, 0.741, 0.785, 0.711, and 0.791, all of which can be factorized. The results are shown in Table 3.

### 4.2. Main influencing factors of technological innovation in PV enterprises

Supporting the development of new energy industry, especially the development of photovoltaic industry, is an important way to optimize China's energy structure, ease the uncoordinated development of environment, resource and economic development and achieve energy saving and emission reduction. China's photovoltaic industry is developing rapidly with a huge scale. Its products have a large share in the world market. China has become the world's largest producer of solar cells, exceeding Europe and Japan in solar cell production with an output close to 1/3 of the world's total. In China, crystalline silicon cells are a major factor in the photovoltaic industrial chain, as shown in Fig. 1.

This thesis finds that the innovation spirit of leaders, government policy support, the enterprise culture and the market structure are the main factors that affect the technological innovation of the PV enterprises:

– Leaders' innovative spirit and entrepreneurial innovation activities affect industry innovation. The leader's innovation spirit is the most important part of the enterprise's technological innovation. It is the innovation spirit of top leaders of the enterprise that will encourage and support innovation activities. Whether the leader has the consciousness of innovation and has the strategic vision of development directly affects the strength and process of enterprise technological innovation. Leaders need not only to have their own sense of innovation, but also to encourage and cultivate innovative spirit of all the staff so as to create a good corporate innovation atmosphere and provide support, and leaders should tolerate mistakes in the process of innova-

Fig. 1. Crystal Silicon Photovoltaic Cells

**Table 3. Results of Reliability and Validity of Data**

| Latent variable | Questions | Factor loading | KMO | Cronbach'a |
|---|---|---|---|---|
| Leader innovation spirit(JS) | JS1 | 0.970 | 0.726 | 0.942 |
| | JS2 | 0.958 | | |
| | JS3 | 0.914 | | |
| Corporate culture(WH) | WH1 | 0.969 | 0.761 | 0.963 |
| | WH2 | 0.961 | | |
| | WH3 | 0.952 | | |
| Property incentive(CQ) | CQ1 | 0.963 | 0.752 | 0.957 |
| | CQ2 | 0.962 | | |
| | CQ3 | 0.959 | | |
| Market structure(SC) | SC1 | 0.959 | 0.741 | 0.941 |
| | SC2 | 0.967 | | |
| | SC3 | 0.939 | | |
| Government policy(ZC) | ZC1 | 0.950 | 0.785 | 0.945 |
| | ZC2 | 0.959 | | |
| | ZC3 | 0.961 | | |
| Innovation intention(YY) | YY1 | 0.965 | 0.711 | 0.921 |
| | YY2 | 0.964 | | |
| | YY3 | 0.943 | | |
| Innovation performance(SY) | JX1 | 0.918 | 0.791 | 0.943 |
| | JX2 | 0.899 | | |
| | JX3 | 0.869 | | |

tion. Only in this way can the enterprise have a good environment for innovation.

– Government policy support affects industry innovation. Through the questionnaire, it is found that the local governments have provided a lot of policy support. By comparing different regions, the development of PV industry with high government support policy is more rapid than that with weak policy support. Specific forms of government policy support include the development of relevant planning, support for major photovoltaic power generation projects, photovoltaic power generation demonstration projects and financial subsidies. It is found in the data analysis that a series of government policy support has effectively promoted the technological innovation of PV enterprises.

– Corporate culture affects technological innovation. Corporate culture represents the spirit, goals and values of an enterprise. Although the corporate culture does not directly impact the technological innovation, it will affect the way of technological innovation, which indirectly determines the success of technological innovation. Excellent corporate culture can support and encourage employees to innovate and create a good environment for innovation while the backward enterprise culture restricts the enterprise technology innovation process. Some conservative enterprises without strategic vision are too cautious to make innovations, which hinders the corporate development.

– Market structure affects the technological innovation of enterprises. There are three main market structures: monopolistic market structure, monopolistic competitive market structure, fully competitive market structure. The market structure of monopolistic competition is a kind of market structure between pure monopoly and pure competition. This kind of market structure is the most conducive

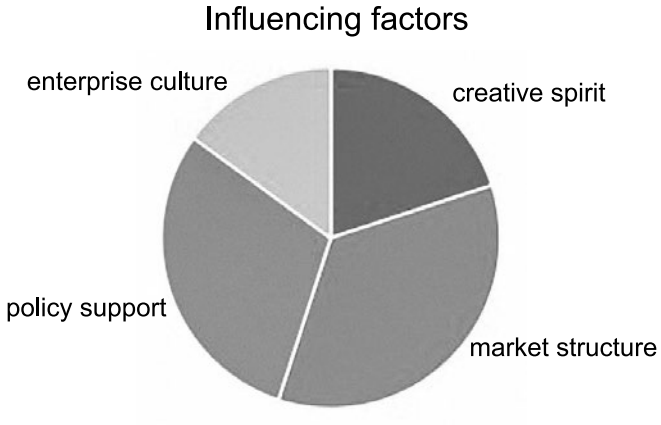


Fig. 2. Main factors of technological innovation in pv enterprises

to the development of technological innovation. In the market environment of monopolistic competition, different products are produced by different enterprises, and such difference not only satisfies the diversified needs of consumers, but also exacerbates the competition among different enterprises. The impact of these four factors is shown in Fig. 2.

In order to stand out and be able to meet the changing needs of consumers, enterprises need to make incessant technological innovation. However, innovation is accompanied with high risks. If enterprises are the only one to assume risks, their innovation enthusiasm will be discouraged to some extent. Therefore, in the market structure of monopolistic competition, enterprises can't do without the support of the government's policy of technological innovation.

## 5. CONCLUSION

Supporting the development of new energy industry, especially the development of photovoltaic industry, is an important way to optimize China's energy structure, ease the uncoordinated development of environment, resource and economic development and achieve energy saving and emission reduction. Despite its rapid development speed and large scale, there are still many problems in China's PV industry such as the lack of core technology, weak policy support and technological innovation, uneven output and domestic market demand, poor innovation performance and inadequate current research on this series of problems. At present, our country is mainly dependent on imports in terms of new energy technology. Through the literature review, expert consultation and questionnaire survey, after analysis of the development of photovoltaic industry in China and the problems in its technological innovation, this thesis obtained the results that the main factors affecting technological innovation are the influence of leaders' innovative spirit (JS), corporate culture (WH), government policy (ZC) and market structure (JG). The proportion of these influencing factors on the PV industry technology innovation is 20 %, 15 %, 30 % and 35 %, respectively. Therefore, it is necessary for China to pay more attention to technological innovation, reduce production costs, improve the efficiency of solar cells, optimize the production process, increase the intensity of high-end equipment research and development, and gradually get rid of dependence on foreign imports to achieve the sustainable development of photovoltaic industry with a strong competitive edge in the international market.

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# THE INFLUENCE OF INTERCULTURAL BUSINESS COMMUNICATION ON THE INTERNATIONALIZED GROWTH OF CHINESE SOLAR PHOTOVOLTAIC ENTERPRISES

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## ABSTRACT

Chinese solar PV enterprises are now in a critical period of internationalized growth. The contradictions and conflicts caused by multicultural collisions have become increasingly obvious at these enterprises. In order to solve the bottleneck problems related to the cultural management in the process of internationalization of these PV enterprises in China, we first analyze the origin and performance of cultural conflicts, and then under the framework of cross-cultural business communication carry out deep discussion about the cultural fusion and the creation of the third culture, so as to discover the approaches with which these enterprises can transform cultural differences into corporate wealth, creativity and competitiveness in the intercultural business communication as well as the ways they can achieve the healthy internationalized growth and sustainable development ultimately.

***Keywords:*** intercultural business communication, photovoltaic enterprises, internationalized growth

## 1. INTRODUCTION

Since the full implementation of the going out strategy, the cooperation in foreign investment of China's solar photovoltaic enterprises is developing rapidly. In the internationalization of enterprises, due to the exchange and collision of different cultures, contemporary managers and researchers have encountered more and more multicultural challenges, so it is urgent to resolve all kinds of intercultural contradiction and conflicts [1,2]. Intercultural business communication has become the key to the cross-cultural management, and an important factor for enterprises to develop healthily in the internationalization [3,4].

In the context of the traditional energy crisis, it is extremely urgent for the development of clean renewable energy, and the global solar PV industry is facing unprecedented opportunities and challenges. Chinese solar PV companies are more and more involved in the international market. Their competitive relationships with other countries have also become increasingly complex. In the next five years, there will be four years when Chinese solar photovoltaic cell production ranks first in the world. 16 PV companies have already listed in overseas markets and 16 – in the domestic market. This industry has created more than 300 billion yuan of the annual output value, and employed over 300,000 people [5]. Over the past few years, the rapid development of Chinese PV industry has also benefited from the better financing application in the international capital market. After Suntech Power listed in the NYSE, TSL in Changzhou, Suzhou CSI, CSUN in Nanjing, JA in Hebei, Yingli in Baoding, Saiwei LDK in Jiangxi, many other Chinese companies have also listed in the NYSE and NSDAQ [6]. These companies raised billions of capital after the listing, so that an explosion-like development and expansion come in the Chinese PV industry. At the same time, some companies, such as M & A, have begun to take measures, strategic alliances and

long-term contracts to expand their industrial value chain fully from the upstream, midstream and downstream. Chinese solar photovoltaic enterprises have entered the period of internalization totally. In general, the internationalized growth of enterprises, on the one hand, stresses the horizontal expansion of the scale of industries, requiring for the development of world-class level, transnational R&D and organization of production, international channels of capital absorption and utilization of global resource; on the other hand, it concerns more about the vertical capacity of enterprises to rise, so that enterprises have to sustainably enhance their ability to use and develop resources, to optimize the entire industry chain, and to cultivate their own core competitiveness. The organic union between enterprises' international development strategy and the growth strategy [7], and the promotion of enterprises' intrinsic ability fuelled by human resources, funds, technology and so on in the international market constitute the important content of the enterprises' internationalized growth. When the enterprises continue to achieve internationalization, and constantly upgrade their own strength at the same time, the entire industry will also enhance the level of internationalization, so as to achieve the optimization and development of the entire industry and their own growth [8,9].

Intercultural Business Communication plays an important role in solving cross-cultural issues in business management. In 1959, intercultural communication was proposed for the first time to solve international business problems caused by cultural differences [10,11]. Later, intercultural business communication gradually developed into an independent discipline. Intercultural business communication is a new concept, in which such three variables as culture, communication and business are organically integrated [13,14]. At the same time, intercultural business communication is also the communication between managers of different cultural backgrounds. It requires organic integration of business disciplines such as business strategy, business objectives, business management, human resource development and intercultural communication disciplines [15]. By cultural communication and integration, a new business context will be established. Intercultural business communication integrates the intercultural communication science and management science to address intercultural issues in marketing, advertising, business negotiation, leadership, team building, human's resources and so on. This is an important part that Chinese solar photovoltaic enterprises can neither bypass, nor ignore in the process of their internationalized growth, Table 1.

**Table 1. Import and export of China solar photovoltaic products**

| year | year on year growth rate of export | year on year growth rate of import |
|---|---|---|
| 2012 | 134.85 % | -1.52 % |
| 2013 | 100.60 % | 45.31 % |
| 2014 | 36.68 % | 37.34 % |
| 2015 | 45.76 % | 14.61 % |
| 2016 | 67.43 % | -9.41 % |

## 2. METHODOLOGY

In today's world, in the political map, the borders between countries are still as clear as before, but an economic map shows in front of us the competitions of financial and industrial activities regardless of borders. From the perspective of the economic field, the borders between countries are gradually disappearing, and the world is becoming a single market, but its personality and differences of culture, which is the software of the enterprise management, are enriched with more features instead of converging with the disappearance of economic borders. The international communication and management of a variety of cultural exchanges and collisions is bound to make contemporary managers encounter more and more cultural challenges, and solve more and more conflicts and contradictions arising from various cross-cultural communications. Multinational companies have brought financial, technical and managerial experience to China, and have become an important part of China's economy. They have promoted the process of China's economic reform and made positive contributions to China's economic development. But multinational companies need to overcome many difficulties to be successful, in which the culture and management of the collision and conflict are the commonest. Therefore, it is imperative to study the cross-cultural enterprise management. The study of cross-cultural communication in enterprise management is the first prereq-

uisite for the research on the cross-cultural enterprise management.

From a broad perspective, the international business communication includes both communications between members of a business organization and external members, and communications between business organizations. From a narrow perspective, the cross-cultural business communication refers only to the behaviour of natural persons in the cross-cultural business environment. This thesis develops from a broad perspective to explore the cross-cultural communication problems of China's photovoltaic enterprises in the international growth. According to the theory of three variables of cross-cultural business communication, in the context of cross-cultural business communication, such three variables as culture, business, and communication interact and integrate organically, resulting in the integration effect and reflecting the dynamic characteristics in the cross-cultural business communication. The thesis expounds the cultural conflicts faced by multinational corporations, joint ventures and mergers among China's PV enterprises from the perspective of the cross-cultural business communication, reveals the root causes of cultural conflicts, discusses effective ways to eliminate cultural conflicts, and explores the framework of the cross-cultural business communication of the cultural integration, proposes the basis of cooperation for multinational companies, joint ventures, mergers and employees: C culture, in other words, the third culture, and calls attention to the cross-cultural business communication in cultural studies.

The research methods include:

– Content analysis: classify the collected enterprise cases and theoretical document and find out the problems in the document, avoiding vaguely unfounded inferences.

– Cultural analysis: when we analyze others from others' culture, there is usually a default cognitive schema. This schema inevitably differs from the actual cultural pattern of others. In the process of cross-cultural business communication, the communicator's pattern of others' culture is constantly revised and refined. In the process of revising and refining, it often produces anxiety, misunderstanding, and even conflicts. In the study of the cross-cultural business communication, the method of cultural analysis helps to raise the awareness of the culture of others, and cultivate cross-cultural communication skills and cross-cultural adaptability.

– Comparative analysis: analyze the influence of cultural factors such as history, religion, literature, art and politics in the internationalization of PV enterprises in China, and find out the causes of cultural conflicts, and then the way to solve the problems.

– Illustration method: with the help of the process diagram, analyze visually the cultural conflict process and cultural integration process.

– Interdisciplinary research: combined with management theory, sociology, history, philology, linguistics and other theories, analyze comprehensively the problems of the cross-cultural business communication of China's photovoltaic enterprises in the international growth.

– Statistical analysis: classify China's photovoltaic enterprises into the international growth data, analyze comprehensively, and then draw conclusions.

– Database: use modern computer, microelectronics, communication technology and other means to collect, classify, and analyze the data of China's photovoltaic enterprises in international growth, and establish the electronic database.

## 3. RESULT ANALYSIS AND DISCUSSIONS

### 3.1. Cultural conflicts caused by enterprises' internationalized growth

Cross-border mergers and joint ventures are one of the trends of economic globalization. They are also common ways of internationalization of enterprises, which can enhance their competitiveness and promote them to expand into international markets and emerging fields. Chinese solar PV companies are also undergoing this process in the process of internationalized growth. In 2008, Suntech acquired successively Germany's Kutler and Japan's MSK, and in 2009 Motech acquired the solar cell module workshop of General Electric in Delaware in the United States. But when companies enter the international market, the contradictions among co-operators with different cultural backgrounds have increasingly emerged. Although the problems in the process of internationalization of enterprises involve many factors such as enterprise management, management idea, development of human resources, decision making and enterprise communication, these factors are directly related

to people of different cultural backgrounds. Usually, people participate in management and communication with their own values, codes of conduct, and ways of thinking, so they will have different understandings or have the opposite views or behaviour in the decision-making of business management. It's difficult to reach a consensus. The contradictions between individuals are no other than the embodiment of the cultural conflicts in the management of multinational corporations. Multinational companies have brought financial, technical and managerial experience to China, and have become an important part of China's economy. They have promoted the process of China's economic reform and made positive contributions to China's economic development. But multinational companies need to overcome many difficulties to be successful, in which culture and management of the collision and conflict is the most common and most long-lasting one. Therefore, the problems and contradictions in the process of multinational corporation management, cross-border mergers and joint ventures, faced by enterprises in internationalization, reflect concretely the cultural conflicts at the management level.

Cross-cultural conflicts are manifested in all aspects of the international business management, and some of these specific management functions are more sensitive to culture, mainly including management philosophy, employee motivation, and coordination of organization, leadership and decision-making of human resources and so on.

In terms of management concept, rooted in different social cultures and influenced by the local culture, the management concepts of different countries are quite different. The management of Chinese and Southeast Asian enterprises, with the traditional Chinese classical philosophy and ideological enlightenment colour of Confucianism, legalists, Taoism and other theories, has been deeply embedded into the oriental cultural system of corporate ethics, corporate philosophy and entrepreneurial spirit. It has formed an original management philosophy. But the formation of western management philosophy, with the development of management theory, absorbed more nutrition from the management ideas of the masters. Therefore, the western business management philosophy is more penetrated in the essence of the thought of scientific management and behaviour management. These differences have caused large conflicts in the process where the joint ventures implement their corporate culture and corporate strategies.

In terms of employee motivation, because of cultural backgrounds and different ideas, the incentives may be expressed in a variety of ways. In the American culture, people's attitude towards work is positive and enthusiastic, and in the Mexican culture, the attitude towards work is manifested as a way of behaving in order to maintain the desired standard of living, a means of subsistence. Due to cultural differences, the attitude and policies of employee incentives of each country are different.

In the coordination of organizations, different cultural backgrounds may lead to a different choice. In Japanese enterprises, the organization and coordination may use a negotiating approach of gentle breeze and fine drizzle, but the American companies may adopt the strict institutional management and restraint method.

In terms of the leadership power, the responsibilities, powers and duties of the departments or persons in charge are usually strictly cleared in the western management, and followed by a series of authorization rules. It makes the enterprises standardized and form an orderly principle for the various ranks in the system. In the oriental culture system, the people-oriented rational pursuit and the attention to the emotional atmosphere of the emotional contact, the advocating courtesy of the rituals can be formed with their own characteristics of the distribution of authority. It is difficult to form the same one with the western model of distribution of authority and use of the way.

In the aspect of human resources management, the oriental culture system follows the principle of people first, virtue first, and in the western cultural system, it advocates a series of strict and scientific personnel management systems, especially in the joint venture management. At present, the multinational cross-cultural conflict mainly shows four characteristics:

– Complexity: the different cultures in different types of enterprises in the formation of different corporate culture models, often show a complex state, and thus show the complexity of the characteristics.

– Progressivity: this kind of cultural conflict is generally in the psychological, emotional, ideological and other spiritual areas, and the result is that people change unknowingly. But this change

requires a long time to show it. So, the occurrence and evolution of the conflict is progressive.

– Internality: culture is based on the concept of ideas as the core, therefore, cultural conflicts are often reflected in the conflict of ideas; thus the conflict for the enterprise is inherent and essential.

– Fusion: cultural conflict and cultural coexistence are always accompanied by the line. The task of cross-cultural management is to find a common culture from different cultures to reflect the essence of various cultural things, so as to survive in a variety of cultural environments.

Typically, the latter part of the merger or joint venture is both the process to complete the merger or joint venture tasks and the process of merging their respective corporate culture. In this process, cultural factors and personal factors determine the success or failure of the companies. The effective and rational use of these two factors is to ensure the key to business success. Human factors are constrained by cultural factors, and cultural factors are reflected through human behaviours. The failure by cultural mismanagement can account for one-third in all failed companies. Most companies have merger syndromes in the early stages of their merger. The phenomenon of cultural conflicts in the merged companies is inevitable and normal, but if the upper manager lacks the consciousness in cultural differences, underestimates the hidden danger that the cultural differences will affect the normal management, and even can't effectively solve the contradictions caused by cultural differences or can't get rid of confusion, they will seriously affect the mutual cooperation and communication, which not only hinders the development of enterprises, but also may even lead to tragedies.

### 3.2. The cultural integration and formation of the third culture

However, after the establishment of multinational corporations or joint ventures in the internationalization of China's solar PV enterprises, we should fundamentally solve the cultural conflicts, and in order to achieve the sustainable development, we must continue to establish a new culture as a new basis for company cooperation.

As shown in Fig. 1, in the enterprises' intercultural activities, A and B represent respectively the parties from different cultural groups with different values, modes of thinking and modes of communication. Grope A and group B collide with each other. Outside the overlap part, it is the cultural conflict area. The collision of A and B will lead to the emergence of culture C, the third culture. The third culture is not the result of the integration of A and B groups, in which neither A nor B is dominant unilaterally. The two business cultural backgrounds are simply combined, but these two cultures absorb the composition acceptable to synthesize the core values for each other. This is the cultural basis for the elimination of cultural barriers and the establishment of bilateral cooperation. The cultural fusion is created through cooperation and seeking common development of different cultures. Through cultural integration, we can seek common ground while reserving differences, integrate differences and enrich human activities. In the framework of intercultural business communication, the best way to solve the cross-cultural conflicts in management is undoubtedly the creation of new corporate culture based on the effective cultural integration. In the management of multinational companies, the third culture, as a basis for cooperation after the integration, can reduce the barriers in the process and even take an effect by half the effort with double results. In the internationalization of the enterprise, the cultural fusion with the common values as the core is the basis and principle of the management of the transnational corporation or transnational merger company. In order to create the management effect of 1 + 1> 2,

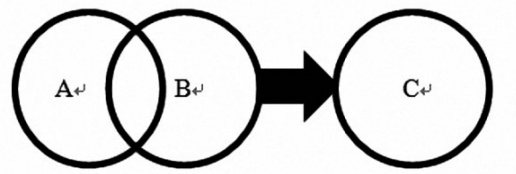


Fig. 1. Cultural integration

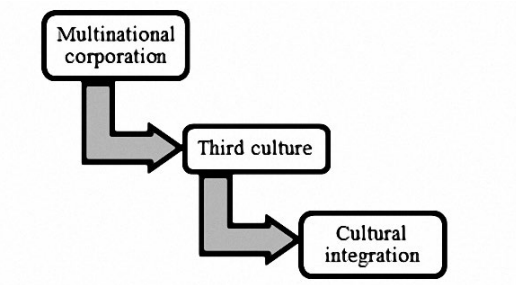


Fig. 2. Formation of third culture

we should establish a new enterprise culture on the basis of cultural fusion, so as to form enterprise strategies, formulate enterprise management system, develop and utilize human resources, evaluate employee performance and develop the market, Fig.2.

### 3.3. Ways of the cultural integration

How can the Chinese solar PV companies achieve the development of multi-cultural integration effectively in the process of internationalization?

Firstly, cultural differences resulting from linguistic differences need to be weakened. In the internationalized life of enterprises, the diversified languages are inevitably involved in all kinds of business activities, and the localities and ethnicity of language is one of the factors most likely to produce cultural differences in business communication. Although international business contacts and interactions are so common today that investors or acquirers can employ local managers or foreigners who are familiar with or understand local cultures and languages to reduce the language barriers, it does not mean that it is unnecessary to learn the local language. In fact, any linguistic community has deep feelings for its mother tongue; understanding and using the other mother tongue can not only bring intimacy, but also help to promote the ideal exchange in order to gain more support. Therefore, in the internationalization of enterprises, we should strive to improve Chinese employees' foreign language skills and foreign employees' Chinese language skills. So the bilingual training for learning and exchanging becomes particularly necessary. This will not only reduce misunderstanding, but also be conducive to the successful agreement and contract. At the same time, two sides in the cooperation approach each other because of the language tightness, which may bring about more favourable conditions. In addition, the reduction of language barriers can also stimulate the enthusiasm of employees of different cultural backgrounds, resulting in the improvement of the productivity.

Secondly, it's absolutely necessary to respect cultural differences, and establish the basic principles in communication with mutual respect, mutual understanding, and equal cooperation. Different values of Chinese and foreign corporate cultures will inevitably lead to differences of management thinking. To eliminate the impact of these differences in values, Chinese and foreign managers and grass-roots employees must have a strong consciousness of cultural differences. Only with the respect for each other's culture and management thinking, would be possible to resolve the problems brought by the differences. Therefore, enterprises should offer both the Chinese and foreign employees not only the basic knowledge of each other's history, customs, traditions, ethics and languages, but also the training of each other's corporate culture and management thinking, which allow Chinese and foreign employees to understand clearly what differences exist between them, and stimulates the strong interest in each other's culture, with a result of truly mutual respect for each other. Only on this basis, can the two sides of the staff carry out equal and friendly exchanges and communication, and understand each other's corporate culture and management thinking deeply, rather than interpret and judge others with different cultural backgrounds by their own values. The ethnocentrism is a terrible obstacle to the formation of a sense of sympathy between people, which not only can lead to communication failure, but also result in antagonism and hostility. Some of the major errors in the internationalization of enterprises are usually derived from the subconscious sense of the national superiority of managers, considering the differences as the issue of cultural merits. Arrogance and self-esteem are both likely to cause mutual disrespect, and even intensify the contradictions. Enterprises can organize various entertainment activities to increase the friendship between employees. In this way, they will better understand each other's behaviour, psychology, etc. The cultural understanding of respective enterprises will also be improved by discussing, exchanging, commenting, and analyzing in these languages and cultural trainings. The manager or even the general staff should be dispatched to others' parent company to study, work, and live for in-depth understanding of each other's corporate culture and management. Through these methods, in the face of divergences, Chinese and foreign managers can more easily think about and solve the problem through communication from the perspective of cultural differences.

Finally, the multinational corporations should also set the unified corporate goals. This is the core of building a cross-cultural communication system for enterprises. Because of the differences in cultural characteristics and the existence of cultural conflicts, enterprises shouldn't identify more advanced

and superior culture subjectively without survey or analysis, and then put it into effect in the culture in all of the enterprises. The integration of culture requires a detailed and accurate investigation in advance and a rigorous analysis of the findings. Different situations need a different way to make cultural integration. At first, from the perspective of cultural characteristics, if the differences are small, based on the use of advanced management concepts, enterprises can inherit the original culture's essence, and replace the original culture by the advanced management mode; on the other hand, if the cultural differences are large, in the early stage of cultural integration, enterprises should take a reserved or separate cultural integration. In addition, we also need to analyze the personnel quality. If the enterprise has some managers of high prestige, or some employees who are high-quality, open-minded and easy to accept new things and foreign cultures, it should show primarily the new culture to these people in the introduction of foreign advanced cultures, and then explain and demonstrate the cultures to other employees through them. On the contrary, we must also take a variety of measures to improve these persons' acceptance of foreign things and foreign culture for playing a radiated role. No matter what the situation is, we should pay a special attention to the role of informal organizations in the enterprise, and create more opportunities to make the informal organizations' leaders get close to and accept foreign culture, wishing their members to imitate consciously or unconsciously through their words and deeds, and gradually learn and accept the new culture, so as to avoid the occurrence of cultural shock and promote cultural integration. On this basis, we can form a unified goal of enterprises, reduce the links of cross-cultural communication, improve the accuracy of information transmission, promote the establishment of cross-cultural communication system, enhance the cohesion of enterprises, and create the core competitiveness of corporate culture in international markets.

## 4. CONCLUSION

Chinese solar PV industry needs to mature rapidly in the internationalized growth to adapt to the trend of economic globalization. Firstly, we should face up to cultural differences. Cultural differences are a natural phenomenon and wealth. Our cross-cultural management research is not to eliminate cultural differences, but to take advantage of these differences, to make them a wealth to improve the creativity and competitiveness.

Secondly, we must enhance the awareness of cultural differences and improve the ability for cross-cultural communication. The different views and opinions of Chinese and foreign managers are normal phenomena. Only by mutual understanding and mutual study, we can overcome the problems of national centralism, seek common ground while reserving differences, and enhance cultural differences and sensitivity.

Finally, the cultural integration is the basis of successful cross-cultural management. We must firstly build the corporate culture on the common values to achieve the cultural integration. The cultural integration should be the primary task of multinational corporations at the beginning, which determines the common basis of two sides for cooperation to avoid the emerging contradictions in the future.

The enterprise's cultural and business communication which determines the success or failure of their international development, to a certain extent, has become the key to obtain strong international competitiveness.

***Declaration of Conflicting Interests:***

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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# PERFORMANCE ANALYSIS OF SOLAR PHOTOVOLTAIC ENTERPRISES' GROWTH DRIVEN BY TECHNOLOGICAL INNOVATION

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**ABSTRACT**

Technological innovation has been the driving force and source of enterprises' development in an era of world economic integration. Only through innovation can enterprises achieve sustainable development. Therefore, this paper is to study technological innovation's impacts on the growth of enterprises, and results show that technological innovation is transformed into the strength of enterprise research and development expenditure. In the paper, technological innovation's impact on enterprise growth performance is analyzed from two aspects, that is, enterprise growth and profit harvest. Results show that the growth rate and efficiency of enterprises are directly proportional to the technological innovation, but they have no significant effect on the profit growth rate, and can't directly create profits value. Research data in this paper provides a basis for the research and development of enterprises' technological innovations.

***Keywords:*** technological innovation, solar energy, enterprise growth, performance analysis

## 1. INTRODUCTION

Innovation has always been the most effective driver for enterprise development in the era when economy promotes development. [1]. Economists put forward the concept of innovation in the *Theory of Economic Development* in early years, and argued that innovation, as a production factor, should be added to the production system [2]. Technological innovation is different from product innovation, in that technological innovation refers to the innovation of production technology, and based on science, it develops new technology, which promotes the growth and development of enterprises [3]. Belonging to the field of industry, technological innovation is an integration process of science, technology and economy, a product of technological progress, and an innovation of the application of double helix [4]. The concept of technological innovation has been widely discussed at the birth of the media, but technological innovation is often used as a slogan, or even reduced to an ideology [5], because people have no clear understanding of technological innovation, which results in limited and one-sided understanding. Their misunderstanding can be divided into two types. One is taking technical innovation as a complete technical behaviour, believing technological progress is technological innovation, and emphasizing too much on technology itself. For example, in reality, many companies have formed a fixed mode of technology development, and they survive and develop without the need for technological innovation. In order to meet economic development requirements, the so-called own research and development team, research and development centres are established. Their research purpose, however, isn't for the development of the market, but to take technological innovation as a means of profit, which makes technological innovation a product [6]. Another is to take technology

innovation as an economic mean, and believes that technological innovation can only exist on the basis of creating economic value. It is clear that this view creates a theoretical deficiency, leading development into the wrong direction [7].

Based on correct understanding of technological innovation, this paper clarified its demand for the impact of enterprise growth. On the basis of relevant theories, this paper transformed technological innovation into enterprise research and development expenditure, established the model of research and development expenditure and the growth performance of the enterprise, and analyzed the performance of the enterprise growth.

## 2. STATE OF THE ART

In 1995, the Fifth Plenary Session of the 14th CPC Central Committee formally proposed to change the way of economic growth. In 2007, the Seventeenth National Congress of the Communist Party of China put forward the demand for accelerating the transformation of the mode of economic development. We can conclude that the state and the Party Central Committee have attached great importance to scientific and technological progress and innovation, taken the scientific and technological innovation as the main line of economic development, and promoted economic development from factor driven to innovation driven [8]. In recent years, many companies have responded strongly to the call of the Party Central Committee, and have developed independent technological innovation, many of which have also won the title of Innovative Enterprise [9]. The State Council unified these innovative companies to provide an in-depth analysis of the relationship between technological innovation and corporate growth [10]. Other companies' awareness of technological innovation has also been woken. In recent years, many economists or business leaders have taken innovation as the core of business growth and have studied it in depth [11]. Foreign comparative research into hundreds of innovative and non-innovative large manufacturing listed companies in the UK found that the profit earning ability of innovative enterprises was stronger than that of non-innovative enterprises, and the growth rate was faster [12]. A research, which analyzed the growth data of nearly 100 listed science and technology enterprises in the German business sector, found that there was a positive correlation between research and development expenditure and the growth of enterprises [13]. Many economic researchers have drawn the same conclusion on similar studies of companies in these countries such as the United States, Canada, and India [14]. The researchers also found that research and development expenditures of enterprises had a positive correlation with the sustainable development of enterprises [15]. There are many factors that affect business growth, but the strength of research and expenditure funding depends on whether the enterprise treats it as a driving force for the market strategy. Through analysis of data of thousands of high-tech enterprises, researchers also concluded that technological innovation only had a positive effect on the growth of a small number of enterprises. We can see domestic research results differ from those of the foreign, so it is necessary to study the impact of technological innovation on the growth of enterprises.

## 3. METHODOLOGY

Based on relevant theories, this paper took the solar PV enterprise as an example, and used the method of first hypothesis after verification to analyze performance of technological innovation on the growth of solar photovoltaic enterprises.

### 3.1. Research hypotheses based on relevant theories

Firstly, for the impact of technological innovation on the growth of solar PV companies it was assumed that the more the expenditure on technological innovation expenditure of solar PV enterprises was, the faster the market growth of the enterprises would be.

Secondly, for the impact of technological innovation on the profitability of solar PV companies it was assumed that more the expenditure on technological innovation expenditure of solar PV enterprises was, the higher the profit performance of the enterprises would be. The profit performance of solar PV enterprises, however, could be divided into two aspects: profit growth rate and profit efficiency. Therefore, this hypothesis was divided into two hypotheses: the more the expenditure of technological innovation of solar photovoltaic enterprises was, the faster the profit growth would be; the more the expenditure of technological innovation of solar pho-

**Table.1. Calculation method**

| Type | Symbol | Change of content | Variable value method |
|---|---|---|---|
| Explained Variable | Growth | Market growth rate | Main business profit margin = main business profit of the first year / main business income of the(t-1) $^{th}$ year |
| | | Profit growth rate | Growth rate of main business profit = profit of main business of the first year / profit of main business of the(t-1) $^{th}$ year |
| | | Growth efficiency | Profit margin of main business = main business profit / main business income |
| Explaining Variable | RD | Research and development strength | Research and development expenditure / main business income |
| Controlled Variable | Size | Size | Natural logarithm of operating income |
| | Age | Age | The number of months of company set up to the end of the t$^{th}$ year |

tovoltaic enterprises was, the higher the efficiency of the enterprise profit would be.

Thirdly, the following assumptions were made on the effect of technological innovation on the growth performance of solar PV enterprises: technological innovation expenditure of solar PV enterprises has a delayed impact on growth performance of the enterprise. The growth performance of solar photovoltaic enterprises, however, included two aspects, that is the growth of the enterprise market and profit growth. Therefore, the hypothesis was divided into the following: technological innovation expenditure of solar photovoltaic enterprises had certain delay.

### 3.2. Study subjects

The research subjects were 20 listed solar photovoltaic enterprises. According to Ministry of science and technology, 10 were rated as innovative enterprises solar photovoltaic enterprises in 2014, among which 5 companies were listed innovative enterprises, and the other 5 companies were listed holding companies. The other 10 were rated as innovative enterprises solar photovoltaic enterprises in 2013, similarly, among which 5 companies were listed innovative enterprises and the other 5 companies were listed holding companies. To serve as research subjects, the 20 solar photovoltaic enterprises needed to provide complete and accurate financial data.

### 3.3. Acquisition of relevant data

Financial summary reports and annual summary files of the 20 solar PV enterprises were collected for 2013, 2014 and 2015; the corresponding research and development expenditure data and other relevant data were also collected.

### 3.4. Establishment of performance analysis model

In line with the hypothesis of enterprise research and development expenditures and the growth performance of enterprises, the following models were constructed according to the hypothesis of the 3.1 part (Fig. 1).

$$growth = \beta_0 + \beta_1 RD + \beta_2 size + \beta_3 age + \varepsilon, \quad (1)$$

where *growth* is evaluation factors and standards of enterprise growth performance, and business profit related to technological innovation was the evaluation subject; R&D is the evaluation factor and standard of technological innovation, and in this paper, it was research and development expenditure; *size* is the size of the firm (the natural logarithm of revenue); *age* is the year of the establishment of the enterprise (the total number of months since the establishment of the company). Specific calculation methods are shown in Table 1.

**Table.2 Statistics and analysis of relevant data**

| Variable | | Minimum value | Maximum value | Average value | Mid-value | Standard deviation |
|---|---|---|---|---|---|---|
| RD intensity in 2013 | | 0.0008 | 0.1252 | 0.0350 | 0.0279 | 0.0318 |
| RD intensity in 2014 | | 0.0000 | 0.1401 | 0.0311 | 0.0208 | 0.0321 |
| RD intensity in 2015 | | 0.0000 | 0.1197 | 0.0339 | 0.0266 | 0.0297 |
| Growth rate of main business income | 2014 | -0.1382 | 1.0769 | 0.2224 | 0.2121 | 0.2559 |
| | 2015 | -0.5371 | 0.8154 | 0.1012 | 0.0743 | 0.2782 |
| | 2016 | -0.3637 | 1.5567 | 0.3636 | 0.3144 | 0.3425 |
| Growth rate of main business profit | 2014 | -0.2589 | 8.8887 | 0.5555 | 0.2121 | 1.6213 |
| | 2015 | -0.5455 | 1.7490 | 0.1523 | 0.2123 | 0.4310 |
| | 2016 | -0.8119 | 7.5030 | 0.6727 | 0.2760 | 1.3888 |
| Profit margin of main business | 2014 | 0.0079 | 0.8787 | 0.2514 | 0.2199 | 0.1575 |
| | 2015 | 0.0199 | 0.8389 | 0.2509 | 0.2232 | 0.1534 |
| | 2016 | 0.0289 | 0.8262 | 0.2614 | 0.2129 | 0.1612 |

After implementing the technical innovation for one year, the relevant data were collected, which studied the delay of technological innovation's effects on the growth of enterprises. Each enterprise's research and development expenses were set to make a one-time allocation at the beginning of each year, so the analytical model was evolved into formula (2), formula (3) and formula (4):

$$growth_t = \beta_0 + \beta_1 RD_{t-1} + \beta_2 size_t + \beta_3 age_t + \varepsilon_t. \quad (2)$$

$$growth_t = \beta_0 + \beta_1 RD_{t-2} + \beta_2 size_t + \beta_3 age_t + \varepsilon_t. \quad (3)$$

$$growth_t = \beta_0 + \beta_1 RD_{t-3} + \beta_2 size_t + \beta_3 age_t + \varepsilon_t. \quad (4)$$

Formula (2) is a test of financial performance one year after research and development expenditures in 2013, 2014 and 2015. There are corresponding financial data in 2013, 2014 and 2015; formula (3) is a test of company's performance two years after research and development expenditures in 2013 and 2014. There are corresponding financial data for 2015 and 2016; formula (4) is to test enterprises performance in 2013, three years after research and development expenses, and there are corresponding financial data for 2016.

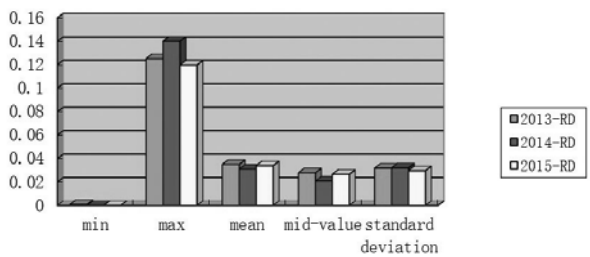


Fig.1. RD from 2013 to 2015

## 4. RESULT ANALYSIS AND DISCUSSION

### 4.1. Statistics and analysis of relevant data

From 2013 to 2015, research and development expenditures are shown in the Table 2. The results show a stable input from innovative solar PV enterprises, and a sustainable implementation of technological innovation. There, however, is a certain difference between the data.

Research and development spending in 2013 has a significant correlation coefficient with business revenue growth in the following 3 years, while that in 2014 has a different correlation coefficient with business revenue growth in the following 2 years, and in 2015, it has a low correlation coefficient with business revenue growth in the following one year. From above results, we can conclude that technological innovation of innovative solar photovoltaic enterprises has a significant role in promoting enterprises' development, but has shorter duration.

The correlation coefficient between research and development expenditure and the qualitative

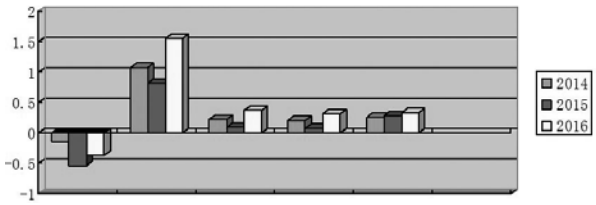


Fig.2.The growth rate of main business income

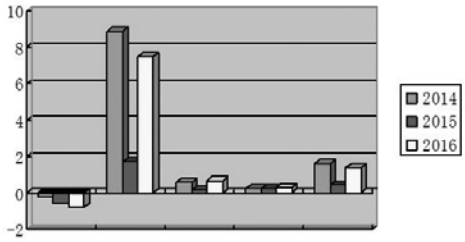


Fig.3. Profit growth rate of main business

change of enterprise growth performance is shown in Table 3. The results show that there is no significant correlation between research and development expenditure of solar PV companies in the period of 2013 to 2015. From the growth rate of relevant business profit in different periods, we can see there is a significant positive correlation with the profit margin of related business. Therefore, we can conclude that technological innovation's effect on the growth of the enterprise is delayed.

### 4.2. Relevant results between research and development expenditure and the growth rate of business income in different periods

As shown in Table 4, in 2013, research and development expenditures on the performance of enterprise growth is regressed. The results show that research and development expenditure of solar PV enterprises in 2013 has a positive correlation with

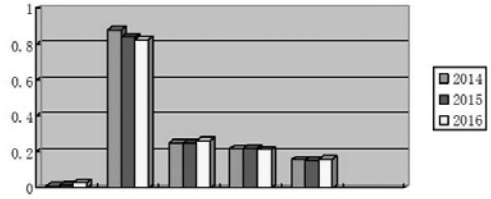


Fig.4.Profit margin of main business

the growth rate of relevant businesses, and the positive correlation lasts for two years after implementing technological innovation, while the duration is around 1 year.

As shown in Table 5, in 2014, research and development expenditures of solar photovoltaic enterprises achieved regression analysis of the growth enterprises' performance. The results show that research and development expenditure of solar photovoltaic enterprises in 2014 has a positive correlation with relevant business growth rate, and the positive correlation lasts for one year after implementing technological innovation, while the duration is around 1 year.

In 2015, research and development expenses of solar PV enterprises would be regression analysis of enterprises' growth performance, and results would be poor.

## 5. CONCLUSIONS

In this paper, 20 solar photovoltaic innovation enterprises were taken as research subjects. The corresponding analysis model was established by using research and development expenditure as the quantitative indicator of technological innovation, and then the impact of research and development expenditure on solar PV companies' growth performance were analyzed. Firstly, it can

**Table.3 The correlation coefficient between research and development expenditure and the qualitative change of company growth performance**

| | | Growth rate of main business income | Growth rate of main business profit | Profit margin of main business |
|---|---|---|---|---|
| Formula (2) | RD in 2013 | 0.2395 | -0.1638 | 0.7140 |
| | RD in 2014 | 0.4343 | 0.2040 | 0.6849 |
| | RD in 2015 | -0.0200 | -0.1333 | 0.2634 |
| Formula (3) | RD in 2013 | 0.4395 | 0.1925 | 0.7143 |
| | RD in 2014 | -0.0240 | -0.1650 | 0.5638 |
| Formula (4) | RD in 2013 | -0.1009 | -0.2366 | 0.6390 |

**Table.4 The regression results of research and development expenditures on enterprise growth performance in 2013**

| | Growth rate of main business income | | | Profit margin of main business | | |
|---|---|---|---|---|---|---|
| | **2014** | **2015** | **2016** | **2014** | **2015** | **2016** |
| Constant term | –0.1730 (–0.400) | –0.5300 (–1.020) | –0.1376 (–0.190) | 0.2534 (1.070) | 0.2204 (0.964) | 0.3844 (1.475) |
| RD | 1.1085 (0.955) | 3.7114 (2.740) | –0.6071 (–0.320) | 3.3197 (5.370) | 3.2896 (5.490) | 2.8932 (4.254) |
| Size | 0.0260 (1.316) | 0.0260 (1.122) | 0.0120 (0.600) | –0.0033 (–0.323) | –0.0026 (–0.231) | –0.0067 (–0.567) |
| Age | –0.0019 (–2.165) | –0.0007 (–0.560) | 0.0008 (0.468) | –0.0004 (–0.784) | –0.0003 (–0.572) | –0.0006 (–1.140) |
| Adj $R^2$ | 0.119 | 0.160 | –0.054 | 0.483 | 0.480 | 0.400 |
| F value | 2.722 | 3.455 | 0.356 | 13.030 | 12.790 | 9.333 |

**Table.5 Regression results of research and development spending on company's growth performance in 2014**

| | Growth rate of main business income | | Profit margin of main business | |
|---|---|---|---|---|
| | **2015** | **2016** | **2015** | **2016** |
| Constant term | –0.3734 (0.655) | –0.0785 (–0.095) | 0.2460 (1.014) | 0.5376 (1.960) |
| RD | 4.0175 (2.895) | 0.0490 (0.026) | 3.2600 (5.600) | 2.4884 (3.650) |
| Size | 0.0163 (0.650) | 0.0160 (0.434) | –0.0049 (–0.475) | –0.0130 (–1.044) |
| Age | –0.0005 (–0.450) | 0.0005 (0.320) | 0.0000 (–0.072) | –0.0006 (–1.140) |
| Adj $R^2$ | 0.142 | –0.067 | 0.433 | 0.313 |
| F value | 3.414 | 0.112 | 12.222 | 7.453 |

be concluded that there is a positive correlation between technological innovation and business income growth of solar PV enterprises, and that technological innovation can rapidly promote business growth, but the duration is shorter. However, the impact of technological innovation on the growth rate of solar photovoltaic enterprise profit is small, which means technological innovation doesn't directly create profit value. The research finds that the technological innovation of the solar photovoltaic innovative enterprises plays a role in promoting enterprises' growth, but it is not sustainable and durable. Therefore, to achieve sustainable development, enterprises should combine market and profit in innovating procedure of their technologies. Research data in this paper can provide some references for future researches in relevant fields.

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# THE INNOVATIVE MANAGEMENT MECHANISM FOR THE ECOLOGICAL ENVIRONMENT OF PHOTOVOLTAIC NEW ENERGY INDUSTRIAL CLUSTERS

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**ABSTRACT**

In order to meet the needs of the development of new energy in a low-carbon economy, it is very important to study the innovation mechanism of industrial clusters. Based on the summary of theories and practices of ecological innovation of industrial clusters in China and abroad, innovative management mechanism of the cluster eco-environment of photovoltaic new energy industry is studied in this paper. Based on the existing problems of the ecological environment of new energy industry clusters, the feasible path for innovation management mechanism is explored on the basis of the original management mechanism. The research data of this paper can provide some basis for the research on the management mechanism of industrial clusters.

***Keywords:*** photovoltaic new energy; industrial clusters; ecological environment; management mechanism

## 1. INTRODUCTION

Under the severe environment with global pollution, low carbon economy featuring low consumption, low emission, and low pollution development mode has brought an unprecedented industrial revolution [1]. Throughout the history of human development, from the primitive wood energy to today stone energy, economic development has been dependent on high carbon emissions [2]. Due to the serious pollution of global environment the reduction of carbon emission and energy consumption have became the world's primary issues. Direction of the development of low-carbon economy will completely change the existing production, politics, economy, trade and other development patterns, leading the world to a new era of energy [3]. Now, low carbon economy has become the dominant direction of global economic development, and it has not only brought changes in the pattern of international market economy, but has also brought severe challenges to our country, which is highly dependent on petroleum energy [4]. The strong demand for low carbon economy has brought about great changes in our way of life, the model of production and values [5]. In the light of low carbon economy, industrial clusters should focus on energy and environment in the process of competition, so as to achieve the maximization of energy utilization and minimization of harm [6]. However, only technological innovation is not enough to meet the requirements of the development of industrial clusters now, so the development of new forms of energy has become the common goal of the development of the world.

In recent years, as a new form of industry, industrial cluster has been developing rapidly in the industrial environment with its large economic scale, low input cost, and comprehensive utilization of intellectual property rights. At the same time,

it has also brought serious negative effects, causing the destruction of ecological environment and a high degree of waste of energy resources. In order to be strongly competitive in the industrial cluster area, some enterprises ignore the protection for ecological environment and the limited development of energy resources [7]. Photovoltaic new energy industry has gradually attracted people's attention under the severe situation. This can be undoubtedly an exciting movement for China in that China covers a large area and enjoys adequate solar energy resources. Photovoltaic energy doesn't have to be exploited in a destructive way. Moreover, emissions of photovoltaic energy are safe and environment-friendly. Therefore, the new energy has huge potential of development not only in our country but also in the world. For the next few decades and even centuries, the new energy will become the main direction of the development of new energy. Therefore, it is necessary to study the innovation mechanism of ecological environment of industrial clusters.

Based on the global demand for the development of new energy sources and relevant theories, the existing development conditions and problems of industrial cluster ecological environment are analyzed in this paper. How to use the innovative mechanisms to solve or minimize these problems is also tentatively explored.

## 2. STATE OF THE ART

With the depletion of non-renewable resources, development of enterprises will be hindered. The development of new energy sources has not only expanded the economic market, but has also increased the carrying capacity of the environment. If enterprises' self-development ability can be improved, then the innovation management of the ecological environment will become the only way to improve the competitiveness for industrial clusters [8]. Researches about the innovation management of ecological environment done by foreign researchers mainly focus on the environment of the enterprise and the internal proceses at the enterprises [9]. Through the studies, some scholars said that the innovative management of ecological environment is one of the ways to improve the performance of enterprises [10]. If the quality of environment can be improved, then the enthusiasm of the staffs can be improved, then the performance of the enterprises can also be improved. The researchers mainly studied the innovation mechanism of ecological environment inside the enterprises. The earliest researches on the innovation mechanism of ecological environment in our country are about the green organic agriculture, and then researches in our country have shifted the focus of studies to ecology and innovative mechanism [11]. Researchers in our country defined the innovation mechanism of ecological environment as the reform of ecological environment and the innovation of production system and economic system. That is to say, social production, enterprise development, people's consumption, and the whole production process need to go through the ecological system innovation, technology innovation and industry innovation, which constitute the three elements of the sustainable development of China's economy [12]. Chinese researchers have proposed that only the innovation of ecological technology, the development of the green system, and the ecological concept can solve the ecological problems that have emerged or are about to emerge [13]. That is to say, theoretical content of the innovation mechanism of ecological environment can be divided into three parts, namely the innovation of green system, the innovation of ecological technology, and the innovation of ecological concept [14]. In this way, a new energy industry which is economically valuable and ecologically significant can be formed [15]. From the strategic perspective, innovation mechanism of the ecological environment of photovoltaic new energy industry cluster mainly contains three aspects; from the macro perspective, the development of ecological environment of the photovoltaic new energy industry cluster needs the innovation to work as a driving force and guidance; the development of ecological environment of the new photovoltaic energy industrial clusters needs to establish an innovation system of ecological environment; from the micro perspective, a new way of innovation and development is the core of innovation mechanism of the ecological environment of the new energy industrial clusters, which is shown in Fig. 1.

It can be seen that, based on the concept of low carbon economy, the innovation of ecological environment of the new energy industry cluster a new connotation has been developed. However, the innovation mechanism of ecological environment is not very clear, which will seriously hinder the future development of photovoltaic new ener-

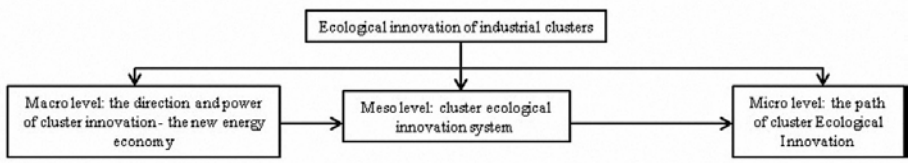


Fig.1. Direction and motive force of ecological innovation in industrial clusters

gy industry. Therefore, it is extremely necessary to study the innovation mechanism of the new energy environment.

## 3. METHODOLOGY

On the basis of relevant theories, from the economic, political, technological and social aspects, the development direction and the source of the ecological environment of innovation mechanism were explored and analyzed. By analyzing the new energy resources of the industrial clusters of ecological system, new ways of innovative mechanism of the industrial clusters of low-carbon energy economy under the new era are explored. Analytical methods and procedures are shown in Fig.2.

## 4. RESULTS ANALYSIS AND DISCUSSION

### 4.1. Analysis of the development direction and power source of the innovation mechanism of the new energy resources of the industrial clusters

After the financial crisis of 2008, some European and American countries used the phrase low carbon economy to restrict the development of some developing countries. Then the financial risk was transferred to developing countries. For example, the U.S. government has set the carbon project as a major economic strategy in the future. Europe, Japan and other countries quickly responded to the green economy concept which is characterized by low carbon emissions, environmental protection and new energy development. And they make it the direction for their future economic development. China's industrial development has been strongly bound by the green economy. But at the same time, the new energy industry represented by photovoltaic energy has become an emerging energy industry with great influence, appeal and guidance. It is helpful for the economic development of our country. And it can provide a powerful driving force for the innovation mechanism of new energy industry cluster of the ecological environment.

Of course, photovoltaic new energy itself is an emerging industry which is conducive to the transformation of China's economy, so it can protect the ecological environment, realize the sustainable utilization of resources, and alleviate the enormous pressure on the ecological environment. This is one of the important manifestations of China's international obligations and an important way to improve China's international influence. Since the reform and opening up, China's economy has been developing rapidly. At present, China's economy is undergoing huge pressures in terms of resources and environmental pollution, so the demand for the ecological environment mechanism of industrial clusters of photovoltaic new energy has become a strong economic force for ecological innovation of industrial clusters in China.

China's former President Hu Jintao has put forward a series of strategy requirements about technical innovation on the Asia Pacific Economic Cooperation Conference, which has technical powers for the innovation and development of ecological environment of the new energy industry clusters.

The development of photovoltaic new energy industry causes the rapid disappearance of produc-

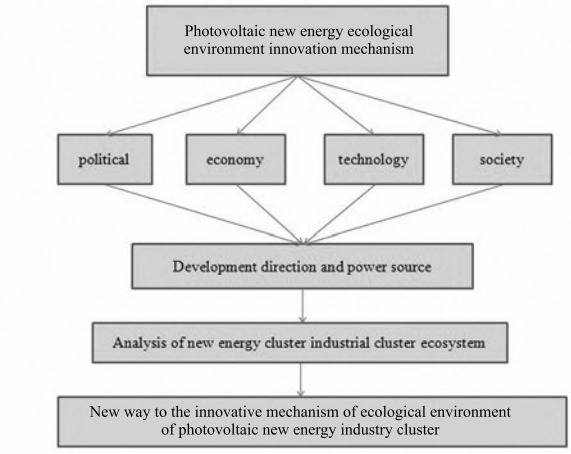


Fig.2. Study process of the innovation mechanism of eco environment of industrial clusters of new photovoltaic energy

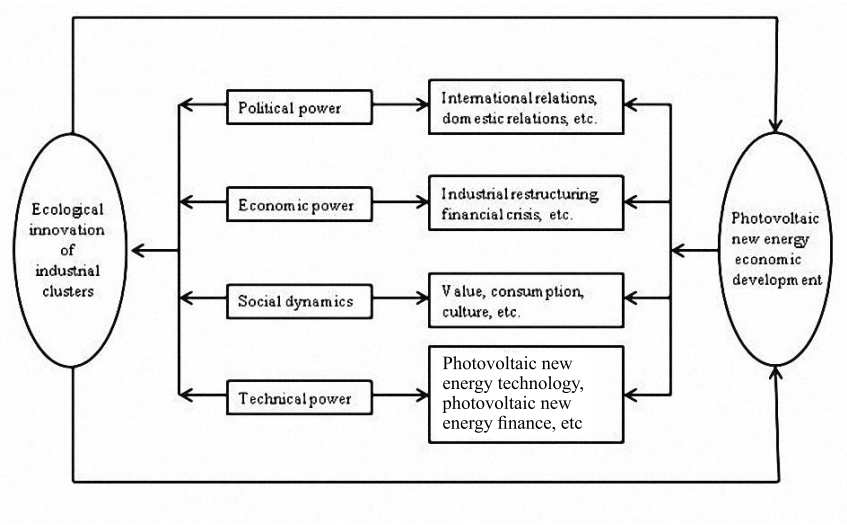


Fig.3. Development direction and driving force of the innovation mechanism of new energy resources of the industrial clusters

tion enterprises, which are highly energy intensive and highly polluted. At the same time, it also changed the way of life and the consumption concept. The concept and awareness of environmental protection have been gradually spread and recognized by the world. The change of and adjustment to these consumption ideas can also provide the social driving force for the innovation mechanism of new energy industry clusters.

In terms of ecological environment, the emergence of industrial clusters of photovoltaic new energy achieves the harmonious coexistence between man and nature, as well as the recycling and re-use of resources, which are development direction of photovoltaic energy. For cultural and social environment, the innovation of photovoltaic energy realizes material and spiritual unity and harmony, providing a clear direction for the application and development of the human system. For the social economic environment, the economic development and social stability, as well as the relief of internal and external contradictions and pressures of the new energy industry cluster are some major development directions for photovoltaic energy. Details can be seen from Fig. 3.

### 4.2. Photovoltaic new energy industry cluster ecosystem

This paper argues that it is necessary to integrate the environment and resources into the new energy industry cluster ecosystem for the reason that the transformation of industrial ecosystem based on the innovation system includes three parts: industrial organization system, ecological system and environmental system. Therefore, ecosystem of the new energy industry cluster is also an ecological innovation system. Ecosystem of the industrial cluster of new photovoltaic energy is shown in Fig.4.

Industrial organization system, ecological system and environmental system are opposite and unified with each other. The antinomy is reflected in the mutual restriction among the three aspects, and the unity is reflected in the mutual promotion relationship among the three aspects. Resource constraints and environmental pollution can lead to restrictions on the development of the core value chain. If the photovoltaic new energy industry cluster ecosystem is in a state of conflict among ecology, environment and organization, then the situation will continue to deteriorate and form a vicious circle, causing the dependence of new energy industrial clusters on determinate path.

Future development of the industrial clusters of photovoltaic new energy system should fully demonstrate the advantages of the industry. Before the establishment of innovative mechanism, independent innovative activities should be carried out by government's supportive policies, by scientific and research public discussions, and by higher education institutes support. After the establishment of innovative mechanism, government should promote the production of high-tech products through multiple assistant policies and programs, so as to shift the government's innovation from supporting the projects of photovoltaic energy industry

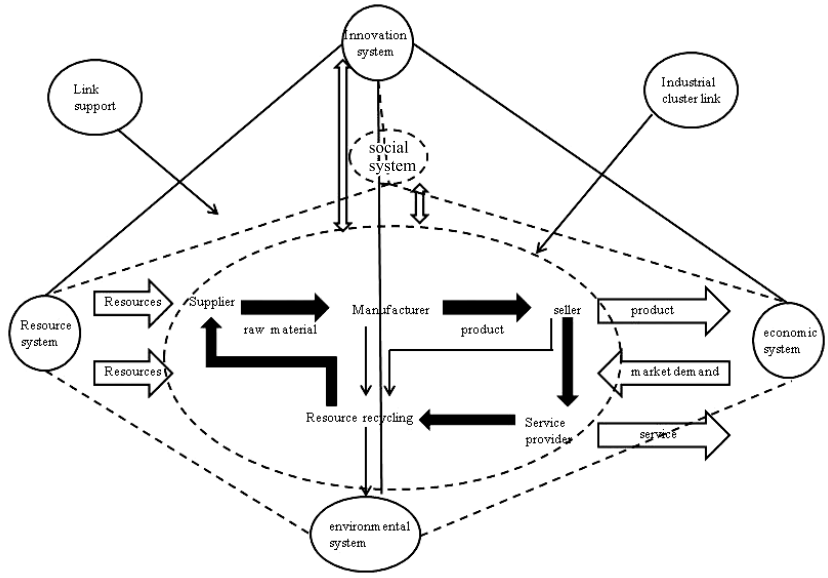


Fig.4. Eco – innovation system based on photovoltaic new energy industry cluster

to supporting the ecological system of photovoltaic energy industrial clusters.

### 4.3. Path for the innovation of ecological environment of photovoltaic new energy industry clusters

Under the current international conditions, the innovation of ecological environment of the new energy industry clusters can be carried out by the following three ways. Firstly, integration and optimization of the construction of photovoltaic new energy society should be conducted at the state level. Secondly, innovative system for regional ecological environment of photovoltaic new energy should be established and industrial development should be coordinated at a regional level. Thirdly, industrial allocation should be optimized and ecological environment resources should be innovated at the cluster level. Concrete path for the innovation of ecological environment of photovoltaic new energy industry clusters is shown in Fig. 5.

In the aspect of national and social construction, researches on the innovation of ecological technology with the combination of cleaner production and ecological structure as its core should be strengthened. Meanwhile, a comprehensive industrial eco-chains with low energy consumption, low emission, and low pollution as its tenet should be established. These measures are also the premise and basis for the innovation mechanism of industrial clusters. Secondly, enterprise economic system and management system should be established to meet the needs of the times. Finally, the establishment of a sound market mechanism can't be ignored. Large scale of the establishment of photovoltaic new energy in-

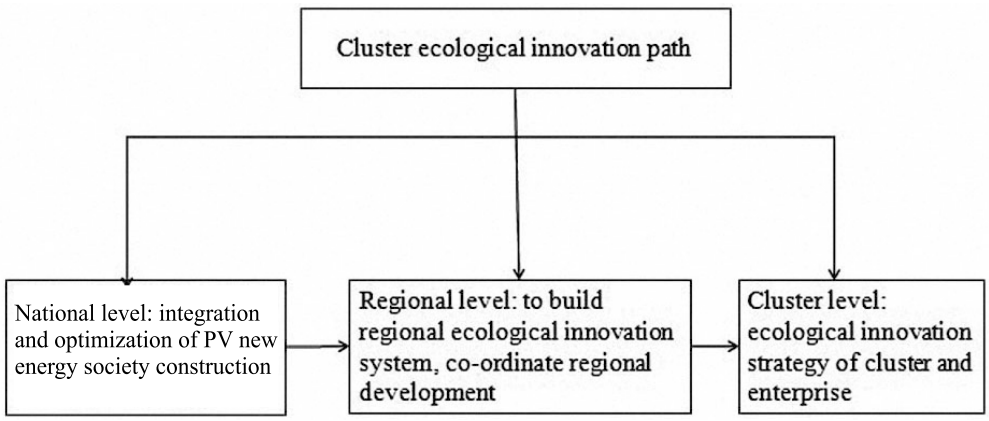


Fig.5. New path of ecological innovation of PV new energy industry cluster

dustry is not enough. Innovation for the development of the industry and eco-environment can be promoted through the protection of laws and regulations. In the aspect of regional coordinated development, plans should be made for fully utilizing the advantages of different regions and making up the deficiencies of the regions in terms of photovoltaic new energy industry. Finally, the innovation mechanism of ecological environment of photovoltaic industry should be adjusted to coordinate the innovative development of regional eco-environment. Industrial clusters, should actively adapt to the requirements of the new energy society and minimize the competition effect among industrial clusters, so as to reduce the economic pressure of the enterprises. However, the update of ecological technology will often result in the market instabilities of corresponding products, which will hinder the development of the whole market. Therefore, while improving the ecoenvironment and making technological innovation, photovoltaic new energy enterprises should squarely face the competitive stress, brought by market economy, strengthen the market innovation, change people's concept about consumption, and cultivate a new concept of consumption, so as to provide necessary prerequisites and preparatory work for the development of photovoltaic new energy.

## 5. CONCLUSIONS

This paper has discussed and analyzed the development direction and dynamic sources of innovative mechanism for eco-environment from aspects of economy, politics, technology and society. Composition of the ecological system of new energy industry clusters and new way of the innovative mechanism of the industrial clusters of new energy industry in the low-carbon economy era are analyzed. Conclusions of this paper are as followings:

– The serious competition among the photovoltaic new energy industry clusters has hindered the development of the industry.

– The photovoltaic new energy industry clusters should fully make use of their characteristics of cooperation, communication, and mutual benefits to avoid the competition within the clusters, effectively use the support policy and incentive system to solve the corresponding problems, solve the problems in the early stage of the development of the existing industry.

– Supportive policies and incentive system should be used to solve problems existing in the early stage of industry's development. Driving forces brought by the government, economy, society, and technology should be fully utilized for innovation of the eco-environment for new energy industry, appropriately reduce the cost price of corresponding product, promote the transformation of people's consumption concept, and create a new era of photovoltaic energy in the future.

In this paper, the structure and development of the photovoltaic new energy enterprises in China are comprehensively analyzed. Although there are disadvantages in this paper, it can still provide references for researches on the innovation mechanism of China's new energy industry.

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# GOVERNANCE MECHANISM OF THE EXCESS CAPACITY OF THE PHOTOVOLTAIC ENTERPRISES FROM THE PERSPECTIVE OF TECHNOLOGICAL INNOVATION

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**ABSTRACT**

This paper first reviewed application theories of technological innovation in excess capacity management of the photovoltaic industry. Second, the current situation in the excess capacity of photovoltaic enterprises and corresponding causes were analyzed. Finally, specific countermeasures based on technological innovation were proposed. Results demonstrated that the excess capacity of Chinese photovoltaic enterprises is characterized by concentrated low-end links in the industrial value chain, surplus of various photovoltaic products, low-efficiency capacity cluster in the short run, and staged excess capacity. The excess capacity of Chinese photovoltaic enterprises is mainly due to four reasons: poor competitiveness of photovoltaic products and overreliance on the importation of technologies, continuous low-level redundant development due to the low access threshold of the industry, poor product and technological R&D capability, and lack of proprietary intellectual property rights. To solve the issue of excess capacity and improve the core competitiveness of Chinese photovoltaic enterprises, photovoltaic technologies should be imported, and independent innovation should be strengthened by constructing a sound (industry-university-research) cooperation mechanism. Moreover, the access system needs to be perfected, the technical standards of the industry need to be regulated, and the financial support system for technological innovation of photovoltaic products should be improved. Research conclusions can provide certain references for future studies on solutions to the excess capacity problem of Chinese photovoltaic enterprises and for the creation of a feasible management plan based on technological innovation.

***Keywords:*** technological innovation, photovoltaic enterprise, excess capacity, management mechanism

## 1. INTRODUCTION

Various countries consider the development and utilization of solar energy as the main content of energy reform. Thus, they have vigorously developed the photovoltaic industry and issued a series of policies to support the rapid development of photovoltaic enterprises. Given the support from government policies and high market demand, the photovoltaic industry has made progress in relevant technological R&D, product scale, and market development. China also considers the photovoltaic industry a strategic emerging industry that requires key support. In response to the macroscopic policy of China, local governments have taken the initiative to undertake photovoltaic industry development planning and encourage photovoltaic enterprises to increase investments for scaled production. A significant number of photovoltaic enterprises

have emerged in China over a short period. However, most of these enterprises have low technical levels and outdated equipment. The numerous photovoltaic enterprises and scaled expansion have resulted in the excess capacity of Chinese photovoltaic enterprises, especially for solar cell and component assembly in the midstream of the photovoltaic industrial chain.

## 2. LITERATURE REVIEW

Some Chinese studies have focused on the theory of excess capacity but have not made any significant achievements yet. Through a comparison of excess capacity in China and in foreign countries, Jiang Hesheng et al. found that excess capacity in China is structural and manifests as a surplus in low-tech processing and assembly products yet with a shortage of high-tech products and services [1]. Zhang Hui discovered that China's excess capacity is mainly caused by long-term, low-level redundant development. He also pointed out that excess capacity is a universal economic phenomenon in the commercial market and is divided into reasonable and unreasonable excess capacity. The former is closely related to the business cycle, whereas the latter is caused by incomplete industrial data and the imperfect structure of business units [2]. Technological innovation, which is one of the impetuses of enterprise development, is widely studied. Meng Fanrong summarized previous research results and argued that technological innovation of enterprises involves exploring, developing, and marketing of new technologies and products. He also indicated that technological innovation produces and launches new products to the market and uses new element combinations that emphasize commercial application in product innovation (e.g., new technologies, and processes) [3]. Li Xiaomei conducted an empirical study on the influencing factors of high-tech enterprise performance and found that technical factors influence the innovation performance of emerging high-tech enterprises [4]. Some scholars have studied the applications of technological innovation in the photovoltaic industry. Shimizu et al. conducted an empirical study on the Japanese photovoltaic industry and observed a cycle of technological R&D and market growth. Such a cycle increases production efficiency, decreases production cost and market price, and stimulates market demand by guiding photovoltaic enterprises to invest in technological R&D [5]. Jacobsson et al. discovered four characteristics of technological innovation in the German photovoltaic industry, namely, support of government policy, multi-agent cooperation, combination of market formation and technological incentive policies, and technological innovation and diffusion [6]. Foxon et al. discussed photovoltaic technology innovation in Great Britain and divided the photovoltaic innovation system into conventional photovoltaic innovation, which involves the reconstruction and updating of existing technologies, and new photovoltaic innovation, which emphasizes fundamental research [7]. Wang Liguo et al. analyzed the technological innovation of Chinese photovoltaic enterprises based on the technical route of solar cell development and concluded that R&D investment in photovoltaic technology and eliminating low-tech enterprises are the key to guaranteeing product quality [8]. Few studies focus on excess capacity of photovoltaic enterprises from the perspective of technological innovation. Zhu Fuliang believed that backward technology and weak innovation are the underlying causes of excess capacity. However, technological innovation could not adapt to changes in market demands, and low-level redundant construction results in structural excess capacity. Excess capacity also reduces sales volume and profits, neglecting R&D investment and fierce competition of low-end products, thereby forming a vicious cycle of excess capacity [9]. Li Jing et al. discussed the influences of technological innovation on excess capacity by using an analytical model and found that the externality of R&D activities (e.g., technological innovation of enterprises) might mean that the innovations of enterprises are freely shared with other enterprises, thereby decreasing their interest in technological innovation and resulting in low-level redundant construction and excess capacity [10]. The literature review indicates that the excess capacity of Chinese photovoltaic enterprises is related to low-level relative surplus, which could be relieved effectively by technological innovation [11]. However, Chinese scholars mainly focus on technological route and application, and their studies lack a systematic analysis of technological innovation for the photovoltaic industry. This issue provides a research gap that this paper seeks to address, as well as a new direction that will allow Chinese photovoltaic enterprises to address the issue of excess capacity.

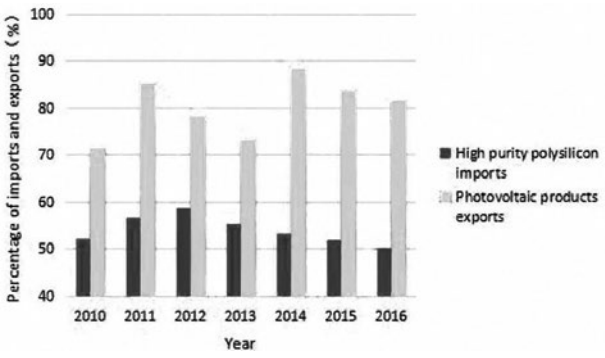


Fig. 1. Proportion of high-purity polysilicon imports and photovoltaic product exports
*(Data source: Data statistics of the Silicon Branch of China's Non-ferrous Metals Industry Association from 2010–2016)*

## 3. CURRENT SITUATION

### 3.1. Excess capacity concentration in low-end links of the industrial value chain

The photovoltaic industrial chain involves upstream, midstream, and downstream. The upstream mainly includes photovoltaic technological R&D, product design, and silicon material production. The midstream mainly includes manufacturing, processing, and assembly of solar cell and solar module. The downstream mainly covers the integrated installation of solar power systems, marketing of terminal products, and brand planning. The upstream and downstream have the highest added value and rate of profit, while the midstream has the lowest added value and rate of profit, thereby belonging to the low-end links. From the perspective of actual photovoltaic industrial development in China, Fig. 1, almost 50 % high-purity polysilicon was imported from 2010 to 2016, while the proportion of photovoltaic products exports was higher than 70 % and was close to 90 % in 2014. Chinese photovoltaic enterprises have high output in the midstream with low added value but have low output in the upstream and downstream with high added value.

### 3.2. Excess capacity of multiple photovoltaic products

Rate of capacity utilization is the basic index to judge excess capacity. Generally, an 85 % rate of capacity utilization indicates full use of capacity. If the rate of capacity utilization is lower than 79 %, then a risk of excess capacity exists. If the rate of capacity utilization continuously remains higher than 90 %, then production capacity is insufficient. According to the statistics of Silicon Branch of China's Non-ferrous Metals Industry Association, China's industrial silicon output was $236\times10^4$ tons in 2016 or approximately 78 % of the global output. The high output exceeded domestic market demand, and the proportion of exports was higher than 50 %. A serious excess capacity of photovoltaic cells and components was observed, manifesting through higher supply than demand. China's Photovoltaic Industry Association's statistics on the rate of capacity utilization of the Chinese photovoltaic industry in recent years, Table 1 indicated that China's polysilicon output was almost 200,000 tons from 2011 to 2016, but the rate of capacity utilization was only almost 30 %. Midstream products such as photovoltaic cell and components have a relatively higher rate of capacity utilization (>50 %), but it is still lower than 79 %, thereby indicating high excess capacity. Therefore, Chinese photovoltaic enterprises are faced with excess multiple photovoltaic products as evidenced by the output and rate of capacity utilization.

### 3.3. Low-efficiency capacity cluster in the short run

The excess capacity of Chinese photovoltaic enterprises indicates low-end and low-efficiency excess capacity instead of absolute excess capacity. In terms of photovoltaic production volume, only the production capacity of polysilicon in China in 2010 exceeded actual international demand. Numerous Chinese photovoltaic enterprises with small-scale production capacity and low technological level have become involved in polysilicon manufacturing given the high added value and profits of upstream polysilicon. As a result, low-level photovoltaic production capacity accumulated and caused the supply to exceed the demand. However, converting most of these low-efficiency photovoltaic production capacities into actual output in the short run is difficult, thus failing to meet domestic demand. Corresponding products have to be imported to offset supply shortage.

### 3.4. Staged variation of excess capacity

The excess capacity of photovoltaic enterprises caused by the failure of market demand to meet the minimum expanded production capacity is tem-

**Table 1. Rate of capacity utilization of polysilicon, solar cell, and components in China**

| | | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|
| Polysilicon | Production capacity (10,000 tons) | 25.1 | 20 | 26 | 39 | 52 | 51 |
| | Output (10,000 tons) | 8.4 | 7.1 | 8.6 | 13.6 | 16.5 | 18 |
| | Rate of capacity utilization (%) | 33.47 | 35.50 | 33.08 | 34.87 | 31.73 | 35.29 |
| Solar cell | Production capacity (GW) | 21 | 23 | 25.1 | 33 | 41 | 49 |
| | Output (GW) | 11.1 | 12.2 | 14.5 | 18 | 22 | 27.6 |
| | Rate of capacity utilization (%) | 52.86 | 53.04 | 57.77 | 54.55 | 53.66 | 56.33 |
| Components | Production capacity (GW) | 40.1 | 44 | 52.6 | 69.6 | 76 | 98 |
| | Output (GW) | 21 | 23 | 27.4 | 35.6 | 43 | 52.3 |
| | Rate of capacity utilization (%) | 52.37 | 52.27 | 52.09 | 51.15 | 56.58 | 53.37 |

porary. Moreover, photovoltaic power generation is different from traditional energy sources, which are experiencing a shortage and cause environmental pollution; thus, photovoltaic power generation has advantages that other new energies do not have. The Electric Power Research Institute estimated that renewable energy power generation in China will have a total installed electricity capacity of 25 % by 2050, 5 % of which comes from photovoltaic power generation. The excess capacity problem will be solved gradually with the upturn in the international economy and the continuous development of the photovoltaic industry. Therefore, the excess capacity of China's photovoltaic enterprises is temporary.

## 4. CAUSE ANALYSIS

### 4.1. Photovoltaic enterprises rely on technological imports, and photovoltaic products have poor competitiveness

China has issued many policies that pertain to trading the domestic market for technology, thereby making foreign photovoltaic technology diffusion a major source of China's technological upgrade. Similarly, most transnational photovoltaic enterprises in China establish cell module package factories with low added value first because of the vertical division of labor in the product chain. On this basis, they increase the trading volume of photovoltaic products in their homeland by using the cheap labor force in China while maintaining photovoltaic technological advantages. Most of the economic profit of the photovoltaic industry is still gained by foreign investors. As a result, Chinese photovoltaic enterprises rely too much on technological imports. Thus, the development of the photovoltaic industry is restricted and ultimately results in excess capacity. High commodity homogeneity is another reason for overreliance on technological imports. The photovoltaic product market is dominated by vicious price competition rather than technology and quality competition.

### 4.2. The low access threshold of photovoltaic industry leads to low-level redundant construction

Without sound access and environmental protection standards for China's photovoltaic industry, access to threshold is low. The accessing of a great number of weak photovoltaic enterprises causes frequent low-efficiency competition among large-scale photovoltaic enterprises with high energy consumption and environmental pollution. For instance, Linuo, Taiyu, and Dongying are solar photovoltaic enterprises with a high degree of production automation in Shandong Province and perfect quality monitoring and guarantee systems. However, they

are less technologically competitive than foreign photovoltaic enterprises, thus resulting in frequent low-level redundant construction and poor market competitiveness. In additional, the state only emphasizes the development of the photovoltaic industry and neglects to improve access standards, thereby causing redundant construction of low-level photovoltaic bases. Instead of technological innovations, more than 30 provinces and autonomous regions in China misunderstand the scaled development of the photovoltaic industry as an emerging industry. Among 600 cities in China, 300 have photovoltaic solar industries and more than 100 have a photovoltaic industrial base, thereby indicating serious redundant construction and resulting in significant excess capacity.

### 4.3. Poor technological R&D capability determines low product quality

Companies lack R&D investment in high technologies and only optimize existing photovoltaic technologies. Therefore, the produced and processed photovoltaic products are of low quality. Moreover, the state offers few policies and capital supports to technology R&D of photovoltaic enterprises, thereby causing a serious industry-university-research disjunction. No large photovoltaic industrial research center exists, technological innovation of most photovoltaic products is rare, and laboratory tests are few. Improving product quality is difficult, and generating excess capacity is easy.

### 4.4. Proprietary intellectual property rights and photovoltaic products separate from new technologies are lacking

Chinese photovoltaic enterprises possess backward technologies and lack proprietary intellectual property rights in terms of high-purity polysilicon output. According to incomplete data statistics, only a few patents of Chinese photovoltaic enterprises are used commercially and are far fewer than those of developed countries. Table 2 shows that from 2015 to 2016, the percentage of China's new utility photovoltaic patents and appearance design is approximately 36 %, and the percentage of patent invention was only almost 26 %. These figures are related with the low proportion of proprietary innovation in patents. Japan has been focusing on patent invention of photovoltaic products, achieving a percentage of more than 61 %. Chinese photovoltaic enterprises are also weak at integrating imported technologies and at secondary innovation. Most photovoltaic enterprises imitate other products instead of innovating their own.

## 5. COUNTERMEASURES BASED ON TECHNOLOGICAL INNOVATION

### 5.1. A sound industry-university-research cooperation mechanism needs to be established

China needs to accelerate the establishment of a sound industry-university-research cooperation mechanism to promote photovoltaic technological innovation and improve product quality. First, Chinese photovoltaic enterprises must enhance cooperation with universities and research institutes, as well as use their equipment and talents. Second, they should integrate their resources and those of research institutes to construct a scientific research base for enterprise-dominated cooperative research and technological innovation. All developed technologies must be verified by a pilot plant test, and only those technologies that passed the test should be used commercially. In sum, China must maximize industry-university-research cooperation to promote market demand-oriented R&D of photovoltaic products and improve technological innovation efficiency.

### 5.2. Photovoltaic technologies need to be imported scientifically, independent innovation should be enhanced, and the core competitiveness of the industry must be increased

Chinese photovoltaic enterprises have to import photovoltaic technologies scientifically and increase the core competitiveness of the industry. China also needs to emphasize the effect of independent innovation and adopt various strategies to support independent innovation of enterprises. China should also increase financial investment in photovoltaic enterprises that make independent innovations and offer them referential tax policies. Moreover, China must accelerate the development and breakthrough of key and generic technologies, and further improve the international standing and scientific competitiveness of its photovoltaic products.

**Table 2.Comparison of photovoltaic patent applications between China and Japan**

| | 2015 | | | | 2016 | | | |
|---|---|---|---|---|---|---|---|---|
| | China | Percentage,% | Japan | Percentage,% | China | Percentage,% | Japan | Percentage,% |
| Inventions | 8650 | 26.51 | 8230 | 61.79 | 9230 | 26.26 | 9490 | 61.86 |
| New utility patents | 11530 | 35.34 | 1340 | 10.06 | 13340 | 37.95 | 1570 | 10.23 |
| Appearance design | 12450 | 38.16 | 3750 | 28.15 | 12580 | 35.79 | 4280 | 27.90 |
| Total | 32630 | 100 | 13320 | 100 | 35150 | 100 | 15340 | 100 |

### 5.3. The access system must be perfected, and technical standards of the photovoltaic industry need to be regulated

China has to gradually perfect access supervision of the photovoltaic industry, as well as establish and optimize access standards. First, existing access standards must be adjusted and modified. Second, the government department needs to optimize the access standard system of photovoltaic enterprises and formulate strict norms on energy consumption, environmental protection, and safety standards to prevent low-level, low-efficiency photovoltaic enterprises. Third, a perfect technological standard system for photovoltaic products should be established. The state must encourage photovoltaic enterprises to make technological innovations, improve product quality, and promote high-tech development. Lastly, the access system of the photovoltaic industry must be able to support high-purity polysilicon and energy-saving manufacturing technologies. A photovoltaic product certification and monitoring system needs to be established.

### 5.4. A financial supporting system for technological innovation of photovoltaic products needs to be perfected

A diversified financial supporting system for photovoltaic products can enhance the technological innovation of the photovoltaic industry. Hence, China's photovoltaic industry must increase loan support for small and medium-sized photovoltaic enterprises. However, most credit funds of Chinese commercial banks are allocated to large state-owned and high-tech leading enterprises, and only a small amount is available to small and medium-sized photovoltaic enterprises without mortgages after they meet the high assessment criteria. This issue restricts the development potential of small and medium-sized photovoltaic enterprises. Therefore, China needs to reform the traditional operation and risk monitoring mode of commercial banks, develop a loan program for science and technology, and issue related policies to encourage the coordinated cooperation of financial organizations, including commercial banks, in exploring joint guarantee and loan, and sharing the financial risks of the photovoltaic industry.

## 6. CONCLUSIONS

This paper analyzed the causes and countermeasures of excess capacity of Chinese photovoltaic enterprises from the perspective of technological innovation. Future studies can focus on overall planning for the development of the photovoltaic industry, develop a production capacity test system for photovoltaic enterprises, establish a law and regulation system for new energy exploitation and utilization, learn foreign countermeasures, and enhance macro-control of the government.

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# PHYSICAL EXERCISE AT HIGH-TECH PHOTOVOLTAIC ENTERPRISES

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**ABSTRACT**

In view of the fact that employees of high-tech photovoltaic enterprises don't have enough time for physical exercise in China, this paper explores the main factors that cause this phenomenon and analyzes their correlation degree by Gray Relational Analysis (GRA). The results shows that the top three factors that influence employees' physical exercise are respectively the laziness of the employees, a long working hours and a small number of facilities available for exercise. The aim of this study is to provide a positive impact on the healthy development of employees in our country, and propel a sustainable development of PV enterprises.

***Keywords:*** high and new technology, photovoltaic enterprises, employees, physical exercise

## 1. INTRODUCTION

Along with the development of the society, a large number of enterprises and industries begin to appear in accompanied with the progress of science and technology, which brings not only a lot of convenience for people but also some dangers and limitations to people's life and production activity [1]. Traditional resources are consumed in large quantities along with the rapid development of many enterprises, and the excessive use of traditional resources furthermore brings a certain degree of damage to people's living environment. Since these traditional resources have been formed within a long period of time, the excessive use of these energies will cause the depletion of resources. Moreover, the ecological environment suffers certain damage due to serious pollution caused by the pollutants released in the burning proceses [2]. China is a country of vast territory, and has reserved a great variety of resources. However, due to the limitations of our technology and the increasing demand for resources from the rapidly-developed economy, in recent years, China's resource reserve declines gradually. Many studies show that in the world China's energy consumption per capita is rather low. What's more, along with energy massive consumption, our environment is to some extent damaged with reduced ecological diversity [3]. These above-mentioned reasons lead to the increasingly shortage of resource reserve. At the same time, environmental problems also bring great negative impact to China's economic development. In particular, the acceleration of industrialization and urbanization in China causes not only the increased consumption of resources but also the discharged of a large number of toxic pollutants, which reduces the self-purification capacity of the environment and affects people's health. Considering all these phenomena and factors, it is urgently needed for us to develop and utilize new energy. Today, there are already many PV companies which produce many products for our production and life. They not only provide convenience for our life and production but also save the traditional energy and naturally become an inevitable trend of energy development [4].

The photovoltaic industry develops rapidly in the world with the number of photovoltaic enterprises increase steadily every year. What's more, with the enhancement of human's awareness in energy and environment, more photovoltaic products are

put to use with people concerning more about the energy and environment problems. The development of PV enterprises raises a greater demand for workers to meet their production needs. At the same time, these employees also serve as positive impetus for the development of these enterprises [5]. When considering its future development direction and potential, an enterprise needs not only to analyze the performance of the enterprise but also consider the every aspect of its business operation. As the greatest resource of enterprise development, it is significant importance to give consideration to the comprehensive development of employees of the enterprise since only when employees have the vitality to maintain a high production, can the development of enterprises be empowered and guaranteed [6]. Especially today when China upholds its people-oriented concept, the overall spirit and physical development of its citizens has become the theme of our times. For an enterprise, the improvement of the overall quality of its employees will also enable the enterprises to develop to a higher level. Nowadays, companies of strong overall strength in our country have already started to regard the health of their employees as an important part of the company operation. However, many new high-tech enterprises, which start late and are of relatively weak overall strength, can't invest a lot in their employees' health and sports, so the health state of the employees of these enterprises is relatively poor [7]. This study, therefore, will mainly focus on the emerging photovoltaic companies and analyze the current state their employees' physical exercise to identify the reasons that lead to the lack of their physical exercise in hope that it can provide a scientific basis for the development of the health of high-tech emerging enterprises employees.

## 2. RESEARCH REVIEW

### 2.1. Research into the development of high-tech photovoltaic enterprises

With the rapid development of the world economy, various industries have witnessed a certain degree of development. The demand for resources and energy in many industries is also increasing rapidly, mainly relying on the traditional fossil fuels such as oil, which are non-renewable and have been formed over thousands or even billions of years. The over-consuming of these energies will cause their depletion, damage the environment and cause other problems. In view of this worrying situation, many countries in the world gradually begin to pay attention to the development of new energy and related technology, and have made some progress. Nowadays, new energies, such as water, wind, nuclear and solar are drawing more and more attention from people and are widely used in our production and life. The application of these new energies has become a new trend in industry [8]. As a kind of energy with little impact on the environment, the solar energy, which produces little pollution to the environment and whose use will not be influenced by certain limitations, will be gradually integrated into the performing of city functions, and serve as an energy support for the industrialization and urbanization of our country. The wide application of solar energy has led to the emergence of a new industry, that is, photovoltaic enterprises whose products, aiming to put solar energy into better use, have a high utilization on solar energy and, thereby, can effectively alleviate the energy shortage and other problems in the development of world industries. It also can contribute to the energy conservation and environmental protection; therefore, it is of positive impact and can significantly promote the development of the world economy [9]. China is rich in resources. However, since its reform and opening up, some negative impact has begun to show up along with vigorous development of its industry and great improvement of economy. Some scholars believe that with the development of China's industrialization, resources will play an increasingly important role in people's life and production, since it will be more widely applied and thus poses a higher demand for traditional resources. Moreover, because China has a large population base, its per capita possession of resources is rather low in the world. Besides, the excessive use of traditional resources also causes serious environmental pollution and, therefore, makes the health our citizens a highlighted problem of today's society. Therefore, from the perspective of long-term and sustainable development, the development and utilization of new energy is the theme of today's development. China has been researching and developing new energies, such as photovoltaic cells, etc., Fig. 1. Long before, China has used the photovoltaic cells in its satellites. Because the capacity of early batteries is relatively small, they couldn't be applied into the actual production and life. How-

Fig.1. Development of Photovoltaic Enterprises

Fig.2. Physical Exercise of Employees

ever, with the continuous improvement of technology, high-power photovoltaic cells begin to attract people's attention. Furthermore, with China's increased investment on photovoltaic cells, PV enterprises begin to pop out. High technologies, which are more widely applied into PV enterprises, provide great impetus for them and positively influence their development [10]. At the same time, it is also of practical significance for the comprehensive development of China's economy and environmental protection.

### 2.2. Research on the physical training of enterprise employees

An enterprise, in making plans for its future, needs not only to consider its current situation, but also analyze the enterprise from a long-term perspective so that it can accurately lay out its operation policies, and have a clearer direction for its future development according to its potentials. The increased emphasis on human resources, which serves as a driving force in the development of enterprises, can effectively improve and strengthen the competitiveness of enterprises. In the past, enterprises emphasized more to the working hours of employees, and attempted to improve the efficiency by extending the employees' working hours [11]. To seek the biggest profit, many enterprises even today ask their employees to work more hours. Moreover, to face the fierce competition, many enterprises carry out the policy that the fitness survive which puts more pressure on their employees and to some degree hurts them both physically and mentally. It has been reported that employees in some companies have certain degree of psychological distortions and some even commits suicide because of the pressure. All these phenomena have forced us to focus more on the physical and mental health of employees [12]. What's more, many scholars point out that prolonged working hours may lead to the lower working efficiency due to the increased fatigue of the employees, and threaten their health. Therefore, many scholars begin to put forward some theories to deal with this problem and integrate them into the development of enterprises. They introduce some new strategies and measures to ease the physical and mental health problems of employees while improve their overall strength and effectiveness. Physical exercise has a great positive impact on the improvement of national physical and mental health. People who often participate in physical exercise not only have a strong physique, but also can endure harder work. At the same time, it also can increase people's inner pleasure. Therefore, in Western developed countries, many companies encourage their employees to relax their minds and bodies through physical exercise after work, Fig. 2, which is conducive for employees to complete the company's work more efficiently and also of great importance for the staff's personal health [13, 14]. Many enterprises in China also begin to implement the national policy to take people first, and pay more attention to the health of their employees in the course of their development. Enterprises that enjoy rapid development in particular, give more thought to improve the welfare of their employees when the overall strength of enterprises is advancing. They invest more in physical exercise so that their employees can have more opportunities to exercise, and, therefore, can improve their work efficiency and create a better culture in the enterprises. Furthermore, it is of great practical significance and can positively promote the comprehensive strength of the enterprise and explore its potentials better.

**Table.1 Main factors influencing the physical exercise of the employees in the emerging photovoltaic enterprises in china**

| Level | Correlation index | Number |
|---|---|---|
| Personal aspect | Lack of awareness of exercise | X1 |
| | Relatively lazy action | X2 |
| Enterprise aspect | Longer working time | X3 |
| | Small company investment | X4 |
| Social aspect | Exercise facilities are relatively small | X5 |
| | National public facilities invested are small | X6 |

## 3. METHODOLOGY

### 3.1. Analysis on the status quo of physical health status of employees in new and high-tech photovoltaic enterprises in China

Along with the economic development in China, industrialization and urbanization has become the mainstay of its development model under which many industries and economics have made great development and progress. However, in its rapid economic development, the industry demand for the traditional energy especially oil and other fossil fuels also increases rapidly, which leads to the crisis in energy and environment in our country. In this circumstance, the emergence and development of high-tech photovoltaic enterprises in China, Fig. 3, brings a certain positive impact and impetus for solving China's energy crisis and environmental crisis. However, since the high-tech PV enterprises develops relatively late in China, there are many deficiencies in their development process. For example, they usually rely on the extension of working hours to maximize the profit of the enterprise, which causes the poor state of their employee's health for the lack of exercise. This study is analyzing the current physical state of China's PV industry employees and the reasons behind their poor health and poor physical exercise in hope to provide some theoretical basis and scientific support for the health improvement of the employees of PV enterprises in China.

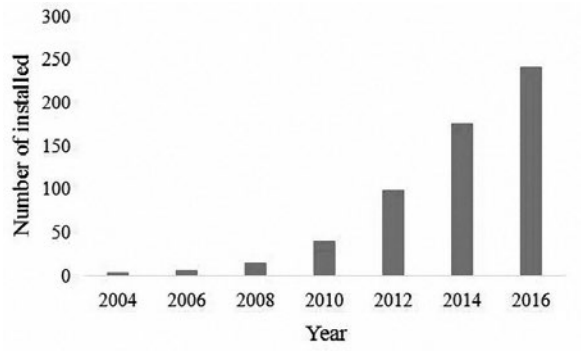


Fig.3. Number of Installed PV Motors in China in Recent Years

### 3.2. Grey correlation analysis (GRA) of factors that influence the physical exercise of employees in the emerging PV enterprises in China

Firstly, this study is using questionnaires, which include questions such as the average exercise time per week of the employees, to collect date to analyze the current physical exercise situation of the PV employees in China.

Secondly, key factors that influence the physical exercise of the employees of PV enterprises are analyzed by GRA to determine the main factors that affect their physical exercise. The main factors influencing the physical exercise of the employees in the emerging photovoltaic enterprises in China are identified by the questionnaire, as shown in Table 1.

Then, the correlation degree of each influencing factor with GRA to determine the most important factors that influence the physical exercise of employees in PV enterprises in China is calculating. The related formulas are as follows:

$$X_b(K) = \frac{X_b^{(0)}(\mathrm{K})}{\frac{1}{\mathrm{n}}\sum_{\mathrm{a}=1}^{\mathrm{n}} Xa^{(0)}(\mathrm{K})} \quad (1)$$

($b$=1, 2, .....$n$; K=1, 2, .....$n$)

$$\varepsilon_a(K)=\frac{\min\min\left|X_b^{(0)}(K)-X_a^{(0)}(K)\right|+\rho\max\max\left|X_b^{(0)}(K)-X_a^{(0)}(K)\right|}{\left|X_b^{(0)}(K)-X_a^{(0)}(K)\right|+\rho\max\max\left|X_b^{(0)}(K)-X_a^{(0)}(K)\right|} \quad (2)$$

$$\gamma_a=\frac{1}{m}\sum_{k=1}^{m}\varepsilon_a(K)(\text{a=1, 2, .....n}) \quad (3)$$

Finally, in view of the present situation and factors that influence the physical exercise of the PV employees, some suggestions are put forward.

## 4. RESULT ANALYSIS AND DISCUSSION

### 4.1. A survey on physical exercise situation for employees in emerging PV companies in X city in China

This survey looks into the weekly exercise time of the employees in emerging PV companies in China's X City. The results are shown in Fig. 4. The survey was conducted randomly on 60 employees of a PV company in X City. The results show that most of the employees (about 51.67 %) have less than two hours of exercise per week, and only a few employees spend 6 to 8 hours (6.67 %) and 8 to 10 hours (5.00 %) on sports. What's more, most employees do sports on weekend.

### 4.2. The analysis results of factors that influence the physical exercise of employees in emerging photovoltaic enterprises with GRA

Data collected from questionnaire to identify the main factors, Table 2, that affect the sports exercise of the 60 employees are calculated and analyzed by the Grey Relational model. The results show that

**Table 2. Correlation analysis of each influencing factor**

| Influencing factor | Correlation degree | Sorting |
|---|---|---|
| X1 | 0.399 | 4 |
| X2 | 0.431 | 1 |
| X3 | 0.430 | 2 |
| X4 | 0.351 | 6 |
| X5 | 0.411 | 3 |
| X6 | 0.379 | 5 |

the laziness of the employees, the relatively long working hours and the insufficiency of exercise facilities are the top three factors that cause the relatively poor exercise state of the employees.

### 4.3. Suggestions and relevant strategies

In order to better ensure the rapid and sustainable development of photovoltaic enterprises, more effective measures should be taken to improve the health of their employees. Therefore, this study, by looking into the opinions and expectation of research subjects, proposes some suggestions and strategies to improve their physical exercise in the future, which are shown in Fig. 5.

## 5. CONCLUSIONS

In the course of economic development, many industries pose an increasing demand on tradition-

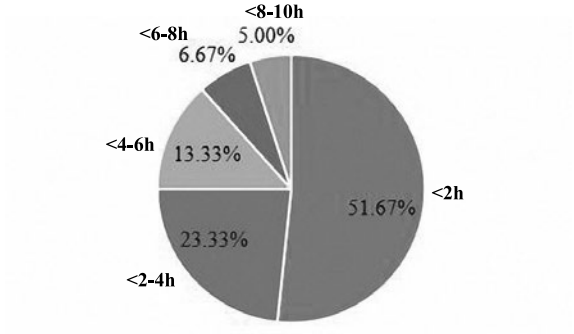


Fig.4. Survey on the physical exercise state of employees in a new photovoltaic enterprise


Fig.5. Suggestions and relevant strategies

al energy, which causes the crisis in energy and environment and other problems. In view of this, new energies begin to draw people's attention. PV companies, which mostly make use of solar power, are helpful in solving many energy and environmental problems. However, many photovoltaic enterprises in China start late and rely mainly on extending the working hours of their employees to achieve their profit, which brings a certain negative impact on the health of their employees. Physical exercise, an effective way for employees to improve their physical and mental health, should be paid more attention. This paper explores the current physical exercise state of PV employees in our country, identifies the main factors influencing the exercise of employees and analyzes the data with GRA. Finally, some suggestions and development strategies are proposed in hoping to ease the problem. The paper is conducted with an attempt to provide some theoretical basis for the development of the physical exercise of PV enterprises' employees in China so that they can enjoy a better health and to provide some scientific support for the sustainable development of PV enterprises.

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# EMPRICAL ANALYSIS OF CORPORATE GOVERNANCE AND INNOVATION PERFORMANCE IN SOLAR PHOTOVOLTAIC ENTERPRISE

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**ABSTRACT**

The knowledge resources of solar photovoltaic enterprises have strong asset specificity, and the governance structure has played an important role in promoting the technology innovation. In the thesis, the authors analyze the relationship between the photovoltaic corporate governance and the innovation performance by using panel data model. The results show that there is a positive correlation between innovation investment and innovation performance. Based on the regression analysis the result shows that the higher the proportion of university ownership is, the easier it will make the transformation of technological achievements; enterprises tend to assume more social functions and are more willing to implement the investment strategy, such as the transformation of research achievements in research and development subsidies, thereby increasing R&D investment, and indirectly improving the innovation ability of the enterprises. On the basis of this, we put forward some relevant suggestions.

***Keywords:*** technological innovation, corporate governance, solar photovoltaic enterprises

## 1. INTRODUCTION

Under the background of the rapid development of the global economy, the environmental problems caused by the economic development are increasingly serious. As the largest developing country in the world, the large-scale development of manufacturing industry has led to the rapid rise in energy consumption in China, and the inefficient use of energy has brought the problem to our long-term development [1]. In the last few years, wind and solar energy has been paid attention to by the government. During the five years of the 12th strategic emerging industry plan, the new energy industry has been envolved [2]. With the economic development, China has realized the importance of the development of new energy, and under the guidance of the policy, with the rapid development of China's photovoltaic industry, China has now become the world's largest producer of solar cells [3]. The internal structure of the companies is constantly improving, and their performance evaluation system needs to be more scientific.

With the advent of globalization and the knowledge economy, the external competitive environment of enterprises has entered a period of rapid change and replacement [4, 5]. The analysis of the internal resources of enterprises based on the perspective of strategic direction can develop better; with the further development of economic strategy and the enterprise strategy theory, the resource-based theory has gradually become the combination of economic, industrial organization theory and organization theory for the whole framework of theoretical analysis [6–8]. Most scholars' studies on enterprise resources and competitive advantage focus on resource heterogeneity, which help companies, gain a competitive advantage. Resources with four heterogeneities, such as: valuable, rare, inim-

itable and irreplaceable, are able to obtain the competitive advantage of enterprise resources [9].

Under the open innovation environment, the knowledge network is an important factor that affects the technological innovation of PV enterprises [10, 11]. Through effective business model, the open design method for R&D personnel and photovoltaic enterprises provides an effective opportunity [12]. The important role of innovation on economic development is known as the Schumpeter innovation mode, which emphasizes the entrepreneurs' ability, which is the re-allocation and combination of the company's internal resources for innovation, so as to improve the production efficiency and the results of technological innovation, regarding invention as exogenous variables [13]. With the in-depth study, based on the innovation model of the Pete, it elaborates on the importance of science and technology research and development activities, namely Pete innovation model II, which takes the research and development and technological innovation as the important endogenous variable, promotes the positive cycle within the enterprise through independent research and development and thus contributes to the enterprises' economic development. Obviously, the definition of innovation can be either macro, or micro; it can not only drive economic development through industrial innovation, but also enhance the competitiveness through the company's technological innovation [14]. It is generally believed that the company's technological innovation comes from the whole process from the generation of a new idea to the research and development, product development, manufacturing and commercialization [15]. It includes not only the technological innovation, but also the product technology innovation.

## 2. METHODOLOGY

### 2.1. Shareholder governance, incentive mechanism and innovation resources allocation

Previous research show that the technological innovation is a process of interaction of elements, and after the input of innovation resources, enterprises need to integrate a variety of innovative elements; there is a complex process of value creation in order to achieve the innovation performance. The so-called innovation incentive refers to the design of the corporate governance system, such as board governance. The executive incentive system will affect the company's choice for innovation behaviours, thereby affecting the company's performance. Therefore, the thesis will put the innovation resources into such two factors as the motivation and supervision of the innovation behaviour. Different governance capabilities of the board determine the innovation incentive effect. The executive incentive system of the influence of the innovation behaviour of company executives works through the effect of company innovation performance on the selection and implementation of the company's innovation strategy, Fig.1.

### 2.2. Research hypothesis

Based on the view of resource power, the size of the control right of the company depends on the importance of its investment resources, and the ownership structure can be regarded as an important indication of the control right. At the same time, the ownership structure, as the most basic arrangement system, can have an important influence on the company's behaviour and strategy. Based on the analysis above, we put forward the hypotheses below:

H1: The shareholding ratio of the company's R&D investment is negatively correlated.

H2: The shareholding ratio is negatively correlated to the company's investment in technical manpower.

The feedback refers to the allocation mechanism of the interests of shareholders of listed companies, and based on the principal-agent-theory, if the cash dividend is higher than that of the managing shareholder, the supervision right will be stronger, and the company is more inclined to pursue short-term gains and give up the pursuit of long-term profits of the company, thereby reducing the investment in research and development. Based on the analysis above, we put forward the hypotheses below:

H3: The dividend payout ratio is negatively correlated to the company's R&D investment.

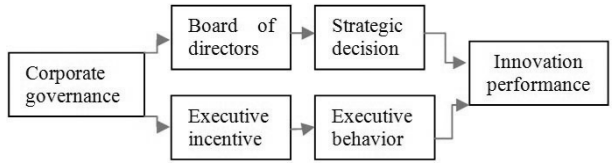


Fig. 1. Innovation performance resource allocation factors

H4: The dividend payout ratio is negatively correlated to the investment in the technical manpower.

The board of directors make decision of R&D investment of the enterprise, and the directors' innovation preference will directly affect the enterprise's, which will have significant positive effect on the innovation preference and of R&D investment behaviour of entrepreneurial team with technological innovation experience, so:

H5: The practitioners experience a positive correlation between the proportion of executives and the company's R&D investment.

H6: Senior managers are positively related to the company's technology investment.

Previous studies indicate that the government subsidies have a crowding-out effect, releasing effect and complementary effect on the investment of R & D in enterprises. Listed companies obtain the sustained government investment, which is bound to increase R&D investment and cultivate the sustainable innovation capability, so:

H7: The government subsidies and R&D investment are positively correlated.

H8: The government subsidies and technical manpower investment are positively correlated.

## 3. RESULT ANALYSIS AND DISCUSSION

### 3.1. Corporate governance structure

The technological innovation performance of solar photovoltaic enterprises is influenced by many factors. Aghion put forward the theory that the enterprise's technology innovation is an endogenous problem, because the innovation of enterprises causes the market competition and changes of the industrial structure. At the same time, more and more scholars pay close attention to the same external conditions; different enterprises adopt different strategies of technological innovation, and the technological innovation theory extends the theory of corporate governance, attempts to explain the reason why enterprises with the same scale and market share have different innovation performances in the same external market environment.

The research of the theory of modern corporate governance has always focused on the conflict of interests between clients and agents, which leads to the gradual development of the core values of agency costs, thus reducing the company's value. The assumption is that the gain control is a subject of interest, and once the control right is acquired, it will seek private benefits and damage the value of the company, so, it needs to design an effective corporate governance system to reduce the agency cost and enhance the value of the company. From the agency cost, the research object of corporate governance gradually expands from the company owners and operators to the stakeholders of the shareholders and small shareholders as well as all the research targets in the company; it gradually changes from the equity maximization into the maximization of company value and benefits of stakeholders; the research framework gradually extends from the enterprise level to the social level.

### 3.2. Variable design

The thesis builds a panel data model to make regression analysis of the relationship between enterprises and innovation ability of the model, by using the software of EVIEWS7, which first carries on the analysis of the data stationary and multi-co linearity, and then make the panel data regression analysis. The model variables are set as follows:

Dependent variable: the R&D investment of dependent variable of listed companies selects the intensity of R&D investment as proxy variables. The data of R&D investment is obtained by the following methods: first, it takes the R&D expenditures as the search keywords through manual inspection of the listed company statements. As for the R&D expenditures of non-open listed companies, in order to maintain the consistency of the index, it selects other cash flow related to operating activities and management fees in the research and development costs, technology development costs, scientific research expenses, research funding, training, consulting, conference fees and test fees as the R&D investment data. In order to make up for the missing value of R&D investment in the past few years, the thesis uses the average sales income to multiply the average annual R&D intensity.

Independent variable: The independent relationship of school enterprise includes the influence of company's shareholders (equity ratio), economic contribution (company cash dividend), experience proportion of executive; the company takes government subsidies as independent variables of the relationship between universities and enterprises. The independent variables of the report of listed companies are accessed manually.

**Table 1.Measure of variable**

| Variable category | Variable name | Variable declaration |
|---|---|---|
| Dependent variable | R&D intensity (R&D) | R&D expenditure/ business income |
| | Technical manpower investment (RPE) | Number of technical employees/company |
| Independent variable | shareholding ratio (OWNEFFECT) | Shareholding ratio |
| | dividend ratio (dividend) | Company's annual cash dividend |
| | Experienced executives proportion (COLLEDGEIN) | Senior management experience (%) |
| | Government subsidy (GOVE) | Government subsidy income |
| Moderating variable | Growth rate of total assets (FGROW) | Company's total assets growth |
| | Operating income growth rate (INCGR) | Operating income growth ratio |
| | Net profit growth rate (IGROW) | Net profit growth ratio |
| | Return on total assets (IFCOM) | Company's net profit / total assets |
| Control variable | company size (SSIZE) | Ttotal assets of the company |
| | Industry dummy variable (INDI) | Dummy variable, the sample belongs to the industry when the value is 1, otherwise when it is 0 |
| | Annual dummy variable (YEARI) | Dummy variable, 1 indicates that the T period belongs to the year |

Moderating variable: According to the life cycle theory of enterprises' growth, enterprises are more inclined to invest in innovation in the developing period to promote the growth of enterprises. Therefore, the thesis selects their growth rate of the total asset, the company's main business revenue, and the company's net profit and the return rate of the total assets as the adjustment variable. However, due to the adjustment of the loss items in the previous year's profit in the annual report, therefore, the adjustment of variable selection is based on the annual report of the adjustment of accounting statements.

Control variable: The enterprise's independent innovation behaviour is affected by the industry, the enterprise scale and so on. The thesis chooses the enterprise scale, the industry characteristic, the annual effect as the control variable. It takes R&D as the research strength, RPE as the investment in technology human resource, OWNEFFECT as the stake, DIVIDEND as the dividend payout ratio, COLLEDGEIN as the proportion of executives practitioners, GOVE as government subsidies, FGROW as the growth rate of total assets, INCGR as the revenue growth rate; IGROW as the net profit growth rate, and IFCOM as the rate of return of the total assets; the model is as shown in formula (1) and (2).

$$RD=\alpha_0+\alpha_1*OWNEFFCT+\alpha_2*DIVIDEND+\alpha_3*COLLEDGEIN+\alpha_4*GOVE+\beta_1*FGROW+\beta_2*INCGR+\beta_3*IGROW+\beta_4*IFCOM+\gamma_1*SSIZE+\gamma_2*INDI+\gamma_3*YEARI+\varepsilon \quad (1)$$

$$PRD=\alpha_0+\alpha_1*OWNEFFCT+\alpha_2*DIVIDEND+\alpha_3*COLLEDGEIN+\alpha_4*GOVE+\beta_1*FGROW+\beta_2*INCGR+\beta_3*IGROW+\beta_4*IFCOM+\gamma_1*SSIZE+\gamma_2*INDI+\gamma_3*YEARI+\varepsilon \quad (2)$$

The variables and data sources above are shown in Table 1. And listed companies R&D investments are shown in Table 2; the China R&D investment intensity of listed companies is generally low, and from 2009 to 2014, companies' average R&D intensity were lower than 5 %, with a rising trend overall year by year; for example, the annual average growth rate of R&D intensity were

**Table 2. Descriptive statistics for the sample group**

| variable | | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|
| R&D (%) | Maximum | 25.85 | 17.08 | 12.66 | 20.29 | 25.87 | 25.30 |
| | Minimum | 0.03 | 0.02 | 0.12 | 0.21 | 0.19 | 0.20 |
| | S.D. | 5.53 | 4.41 | 3.44 | 4.32 | 6.01 | 6.32 |
| RPD (%) | Mean value | 31.46 | 31.83 | 30.85 | 31.21 | 29.35 | 29.29 |
| | Maximum | 87.70 | 87.00 | 84.00 | 82.30 | 79.60 | 75.00 |
| | Minimum | 5.00 | 5.04 | 4.00 | 4.00 | 4.00 | 3.00 |
| | S.D. | 22.64 | 21.60 | 22.68 | 23.00 | 22.51 | 20.59 |
| OWNEFFCT (%) | Maximum | 15.92 | 16.06 | 16.76 | 17.05 | 16.56 | 15.81 |
| | Minimum | 50.15 | 50.15 | 41.18 | 42.28 | 41.38 | 41.38 |
| | S.D. | 0.22 | 0.22 | 1.11 | 1.11 | 0.28 | 1.00 |
| | Maximum | 14.38 | 14.34 | 12.57 | 12.82 | 12.51 | 11.41 |
| DIVIDEND (%) | Maximum | 3.10 | 3.07 | 4.56 | 3.66 | 3.44 | 1.75 |
| | minimum | 32.19 | 27.09 | 69.99 | 29.82 | 62.93 | 10.67 |
| | S.D. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Maximum | 6.56 | 6.40 | 11.55 | 5.85 | 9.30 | 2.74 |
| COLLEDGEIN (%) | Maximum | 29.29 | 27.33 | 24.56 | 24.14 | 22.54 | 24.43 |
| | Minimum | 71.43 | 75.00 | 78.57 | 71.43 | 73.33 | 73.33 |
| | S.D. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Maximum | 19.68 | 18.61 | 17.92 | 17.95 | 16.85 | 17.69 |
| INCGR (%) | Maximum | 11.22 | 15.70 | 16.39 | 14.37 | 18.96 | 9.64 |
| | Minimum | 61.70 | 67.46 | 75.63 | 357.31 | 126.51 | 39.90 |
| | S.D. | -37.29 | -77.91 | -24.68 | -60.85 | -29.56 | -60.41 |
| | Maximum | 23.48 | 25.51 | 20.83 | 57.75 | 30.58 | 19.75 |
| N | | 40 | 41 | 42 | 46 | 47 | 47 |

6.35 %, 18.41 %, 38.24 %, 34.95 % and –1.35 % respectively.

### 3.3. Panel data model

In order to eliminate the problem of time series sample data, the stability test of the panel data is firstly carried out. All the tests were carried out on the stationary sequences by LLC, IPS, ADF, PP and other test methods, in which the original LLP hypothesis testing for the sequence homogeneity has unit root, and IPS, ADF, PP as well as the original hypothesis test for sequence heterogeneity of unit root have been carried out. According to the test hypothesis, all the sample data are stationary after receiving the class-one level differential processing.

In the holding company group, the shareholding ratio was positively correlated with the R&D investment, with the correlation coefficient being 0.053, and the correlation coefficient was significant at the level of 10 %, which indicates that the H1 does not hold shares, and the shareholding ratio has a positive impact on R&D investment decisions. The proportion of the R&D investment of the non-holding group is positively correlated, with the correlation coefficient being 0.057, which is not significant. In the whole sample group, the proportion of shareholding and corporate R&D investment are positively related with the correlation coefficient being 0.053, and it is significant at the level of 5 %.

In the control group and the whole sample group, the proportion of cash dividends and R&D investment were negatively correlated at the level of 5 %,

**Table 3. Regression results analysis of R&D spending**

| Variable | Model 1 | | | Model 2 |
|---|---|---|---|---|
| | Holding | Non holding | Full sample | Full sample |
| OWNEFFCT | 0.053* (1.953) | 0.057 (0.595) | 0.067** (2.479) | -0.656 (–0.463) |
| DIVIDEND | -0.068** (–2.351) | -0.015 (–0.071) | -0.044** (–1.969) | 0.443 (0.187) |
| COLLEDGEIN | -0.033** (–1.981) | -0.055** (2.120) | 0.007 (0.477) | 1.638* (1.619) |
| GOVE | 1.056*** (11.16) | -0.121 (0.808) | 0.689*** (7.282) | -0.073 (–0.01) 0.171 (0.697) |
| FGROW | -0.024*** (–3.987) | -0.002 (–0.497) | -0.006** (–2.488) | 0.17 (0.697) |
| INCGR | -0.017*** (3.621) | 0.0001 (0.419) | 0.0004** (2.120) | -0.000 (–0.051) |
| IGROW | 0.0001 (0.109) | 0.0003 (0.468) | 0.0008** (2.126) | -00040 (–0.976) |
| IFCOM | 0.066** (2.010) | -0.011 (–0.578) | -0.002 (–0.091) | -0.740 (–0.396) |
| SSIZE | 0.002*** (2.831) | 0.003*** (4.302) | 0.002*** (5.577) | -0.078*** (–6.195) |
| $R^2$ | 0.539 | 0.347 | 0.359 | 0.272 |
| N | 26 | 21 | 47 | 47 |
| F | 18.943 | 6.855 | 16.899 | 2.586 |

which indicates that the assumption of H2 is established. To a certain extent, the proportion of cash dividends reflects the short-term profit tendency of listed companies. Holding company group and non-holding company group are negatively correlated, and the level of 5 % is significant; the whole sample group is not significant. This shows that the H3 doesn't make sense. The empirical results of government subsidy income and R&D investment show that the government subsidy income and R&D investment in university -holding group and the whole sample group are positively related to the R&D investment, which is significant at the level of 1 %. This shows that the H4 doesn't stand up. Conditional variables, in holding groups, the growth rates of the company's total assets, main business income and net profit and the return rate of the total assets as well as related R&D intensity coefficient are –0.024, –0.017, 0.001 and 0.066; all of them are significant at the level of 1 % or 5 % except for the growth rate of the net profit. The current total asset yield and R&D investment are positively correlated. Control variables: the size of the company's R&D investment has a significant positive impact on listed companies, and the larger the size of the company is, the more the company tends to invest in R&D.

Based on the data of 47 solar PV companies from 2009 to 2014, the thesis empirically tests the influence of the relationship between the university and enterprise on the R&D investment through the proportion of the stock ownership, the cash dividend and the proportion of the directors. In addition, the listed companies are divided into holding group and non-holding group tested, and the test results show that: for the listed holding group, the cash dividend or university directors have a negative impact on the company's R&D investment, but the proportion of stock ownership and government subsidy in-

come has a positive impact on R&D investment; for group holdings of cash dividends of listed companies, the work of colleges and universities and directors have a negative impact on the company's R&D investment, but the proportion of stock ownership has a positive impact on R&D investment. According to the analysis above, first, as a typical sample of the same organization, the ownership structure of the listed company is perfect, and the administrative link doesn't promote the corporate R&D investment. Second, the higher the proportion of shareholding is the easier support the commercialization of technological achievements changed into investment funds, will get. Enterprises tend to assume more social functions to implement the strategy of investment, such as the transformation of research achievements in research and development subsidies, thereby increasing R&D investment and indirectly improving the innovation ability of the enterprises. Third, make an analysis of the existing literature system based on the cost reduction to encourage enterprise cooperation. So the more the shareholders of the cash dividend are, the stronger the motivation of enterprises with innovation resources to reduce development costs will be, and accordingly the corresponding internal R&D investment will be reduced. Work experience of directors did not have a positive impact on technology investment, mainly from the enterprise director for administrative appointment, the lack of long-term consideration of technology strategy, enterprises pay more attention to short-term benefits to meet the needs of administrative examination, which tends to reduce the R&D investment decision.

## 4. CONCLUSION

The technology innovation performance of solar photovoltaic enterprises is the result of a variety of factors; the process of innovation is to integrate the previous knowledge to obtain a new knowledge of the process. The empirical results show that the relationship between PV company innovation investment and innovation performance are positively correlated. In the high-tech industry of photovoltaic listed companies, increasing investment in research and development is a necessary path for improving the innovation performance. The higher the proportion of university ownership is, the easier it will be to get support for technological achievements for commercialization; enterprises tend to assume more social functions, thereby increasing R&D investment and then improving the innovation capability of enterprises indirectly. Second, the higher the proportion of shareholding is, the easier the commercialization of technological achievements being changed into investment funds, it will be; enterprises tend to assume more of the social functions to implement the strategy of investment, such as the transformation of research achievements into research and development subsidies, thereby increasing R&D investment and indirectly improving the innovation ability of the enterprises. Third, the analysis of the existing literature system is based on the enterprise cooperation for one of the incentives to reduce development costs, the more the shareholders of the cash dividend are, the stronger the motivation of enterprises with innovation resources to reduce development costs will be, and accordingly the corresponding internal R&D investment will be reduced. In addition, the proportion of cash dividends to shareholders has a negative impact on the R&D investment.

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# EMPIRICAL ANALYSIS OF PROJECT MANAGEMENT IN PHOTOVOLTAIC LIGHTING ENTERPRISES BASED ON INTERNAL AUDITING

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**ABSTRACT**

In the face of increasingly severe economic development pressure, in order to improve the competitiveness of enterprises in economic development, China's enterprises must conduct a detailed analysis of the internal audit. In the thesis, China's photovoltaic lighting enterprises were used as samples. The project management at the enterprise was analyzed and studied. The performance of the enterprise was studied through the data distribution of the internal audit model. According to the empirical study of the data, it is found that the independence of internal audit has no significant effect on the improvement of enterprise performance. Therefore, the security function of internal audit has not been fully developed. In the conclusion, the corresponding solution was presented.

**Keywords:** photovoltaic lighting enterprise, internal audit, project management

## 1. INTRODUCTION

The internal audit model refers to the result of the integration of various audit elements with different ways within the enterprise in the specific audit environment. The audit elements mainly include the auditing subject, auditing object, auditing target and other factors [1]. There are five main types of internal audit modes in the enterprise: firstly, the internal audit institution belongs to the financial sector; secondly, the internal audit institution is led by the chief financial officer; thirdly, the internal audit is led by the general manager of the enterprise; fourthly, the internal audit institution belongs to the board of supervisors; fifthly, the internal audit institution belongs to the board of directors [2]. The choice of internal audit mode should be based on the specific enterprise system function and the nature of the audit [3]. At this stage, most of the researches on the audit mode are based on the normative and overall analysis of the internal mode. The thesis analyzed the distribution characteristics of the internal audit mode, and the relationship between the audit mode and the performance, which is based on the research and analysis of the photovoltaic lighting enterprises in China [4]. With the continuous development of the globalization of corporate governance, the internal audit of enterprises gradually developed. In 2002, the board of directors of the internal audit and the senior management of external audit of the International Association of Internal Auditors worked together as the four aspects of effective corporate governance. This is the first time in the world that internal audit and external audit are included in this category, which is conducive to corporate governance.

## 2. STATE OF THE ART

### 2.1. The current status of foreign research

At present, most of the internal audit modes in China refer to, in a particular situation, the results of the integration of various audit elements in different ways. There are a lot of research literatures on the internal audit mode at home and abroad. The analysis of internal audit is mainly embodied in two

aspects: the first one is to explore the subordinating issues in the organization of the internal audit through the point of view of organizational arrangement, and the second is to study the entry point of the audit work from the point of view of the audit method [5]. In the present situation, it is more beneficial to explore the relationship between the internal audit and the enterprise project management from the perspective of organization.

There are many studies on the internal audit mode and research mode at home and abroad [6]. For example, Wallace and Field have found that enterprises with internal audit department are larger and have a more stringent regulatory system. At the same time, their accounting policies are more stable and accountants and managers are more competent. Goodwin and Canter used a proxy framework in 2000 to implement the research on the internal audit of the data of listed enterprises. By contrast, it is found that the existence of internal audit has affected many factors such as the Risk Management Committee, the size of the firm, the asset structure and the audit committee. They also found that the internal audit in the enterprise internal project management is a powerful mean for corporate governance.

### 2.2. The current status of domestic research

Research on the enterprise project management about internal audit of domestic enterprises has just started; by the end of 2005, Lin B.R., Huang C.L. made a detailed analysis of the specific situation of the internal audit of the listed enterprises in China [7]. The study found that enterprises that set up an internal audit department had a larger scale and a higher level than those without a internal audit departments. Then the enterprise of a relatively large scale is more inclined to implement the leadership mode of the general manager, and the enterprise of relatively small size is more inclined to carry out the execution mode with the ministry of finance as the leadership. At the same time, Cheng Xinsheng also found that there are some differences in the specific management mode of the enterprises that have or have not established the internal audit department, but the differences are not obvious. In 2015 Borah R.R, Palit D, Mahapatra S. conducted a further study and analysis on the basis of previous studies; taking eight hundred listed enterprises as the overall sample, they conducted an empirical analysis of the impact of internal audit and financial controls from the audit committee and the internal audit model. The number of enterprises that have set up a model of the relationship between the audit committee and the internal audit is one hundred and forty [8].

Among the 140 sample enterprises, the proportion of those with perfect financial controls accounts for 94 %, and there are 665 samples of enterprises that don't have an audit committee and an internal audit department. Among the six hundred and sixty-five enterprises, the proportion of those without perfect financial control accounts for 69 % [9]. In 2006, Gao Jianxin analyzed the establishment and the effect of the internal audit departments of PV lighting enterprises. The analysis shows that the establishment of internal audit departments of listed enterprises in China plays a certain role in the related management of enterprises. While setting up an internal audit department, we also focus on the management-based analysis and consideration [10].

## 3. METHODOLOGY

With the rapid development of the global economy, it is also facing the energy crisis and a variety of environmental issues in the world. Such problems continue to constrain socio-economic development [11]. Undeniably, the development of photovoltaic lighting enterprises provides a very important strategic significance to ease the energy crisis and the pressure on the environment and implement sustainable development. In recent years, China's domestic photovoltaic lighting enterprises continue to develop; the internal audit of photovoltaic lighting enterprises has played a very important role in its project management [12].

### 3.1. Research background of photovoltaic lighting enterprises

With the support of the relevant departments of China Securities Regulatory Commission, the Enterprise Management Research Center of Nankai University conducted a survey on the establishment and implementation of the modern enterprise system of 1307 listed enterprises in 2003, and made an empirical analysis of the internal audit mode of different enterprises, especially the establishment of the internal audit system. The survey database was used

**Table.1 The internal audit mode distribution of photovoltaic lighting enterprises in China's enterprises**

| Quantity and proportion mode | Internal audit leadership model | | | | | |
|---|---|---|---|---|---|---|
| | Board of Directors | General manager | Board of Supervisors | Financial director | Finance department | Total |
| Quantity | 124 | 117 | 25 | 40 | 36 | 342 |
| Proportion | 36 % | 34 % | 7 % | 12 % | 11 % | 100 % |

as a sample, and invalid sample data (data incomplete) were excluded; there were still 930 valid sample enterprises. In this sample, there were 623 enterprises with internal auditing, accounting for 66.4 % (622/938) of the sample enterprises. The leadership model of the internal audit: 224 led by general manager, accounting for 36.07 %; 52 led by the board of supervisors, accounting for 8.37 %. Through the investigation, it is found that the performance of enterprises that set up internal audit is stable, but the performance of those without internal audit is noticeably deteriorating, suggesting that in the internal audit of enterprises performance plays an important role. Through the internal audit, there are 24 leading modes of the board of supervisors. There are 190 general manager leadership modes.36 financial leadership modes, and 43 CFO leadership modes, as is shown in Table 1.

From Table 1, it is easy to see that in the following leadership models, the proportion of the internal audit mode that belongs to the leadership of the board of directors and the leadership of the general manager is high. These two types of leadership mode account for 70 % of the total market share, while the sum of the other three leadership modes accounts for 30 % of the share. This table shows that most of the internal audit modes of China's photovoltaic lighting enterprises are led by the board of directors and the general manager, and assisted by the other three leadership modes.

### 3.2. The analysis of specific modes

In the detailed analysis from the whole, we need to divide the data into two major modules for analysis. Firstly, the module needs to analyze the listed enterprises that establishes and does not establish an internal audit agency in the photovoltaic lighting listed enterprises. Secondly, the module carries out detailed data analysis of the establishment of the internal audit department of listed enterprises [13]. This is mainly to analyze the indicators: the first one is the performance indicator, operating concept indicator and corporate size indicator. The detailed performance indicators of the internal audit are asset profit margin, net profit margin and net profit ratio in the enterprise. Most of the operating indicators are the asset-liability ratio, operating cash flow, the total assets ratio of internal audit department of enterprise PV lighting, the ratio of operating cash flow and main business income. The vast majority of the indicators that reflect the size are the main business income and the data of the total assets.

### 3.3. The analysis of the first module

In the empirical analysis of the internal audit department, it is necessary to divide the listed enterprises that filled in the questionnaire into two groups. The first group is photovoltaic lighting enterprises that have set up a internal audit (sample number of 309, code 1). The second group is PV lighting enterprises with no internal audits (valid sample 90, code 2). Through the study of these two sets of data, the universal characteristics of photovoltaic lighting enterprises with or without the establishment of internal audit can be analyzed. For the need to strengthen management, as well as the growing need for internal control efficiency, most large enterprises establish an internal audit system and improve enterprise performance through conducting financial audits and managing audits. The following analysis can be made, as it shown in Table 2.

The analysis validates the hypothesis that the listed enterprises that set up internal audits generally have a larger size than those without internal audits. Large-scale listed enterprises usually set up internal audit institutions for two reasons. The first one is the need for management. With the expansion of the business scale and areas, enterprises need to establish internal audit institutions to strengthen management. The second one is to establish corporate image. The establishment of the internal audit institution of large enterprises is conducive to building

**Table.2 Two independent sample tests**

| | Asset profitability | Net profit margin | Return on net assets | Return on assets |
|---|---|---|---|---|
| Mann-Whitney U | 13094 | 13480 | 13345.5 | 13012 |
| Wilcoxon WZ | 17280 | 17666 | 17531.5 | 17198 |

**Table.3 Nonparametric tests for multiple independent samples**

| | Asset profitability | Net profit margin | Return on net assets | Return on assets |
|---|---|---|---|---|
| Chi-Square | 1.5322 | 1.607 | 0.8439 | 3.7171 |
| df | 4 | 4 | 4 | 4 |

a good corporate social system public image. There are differences in the business philosophy and performance of the enterprises that have or haven't established an internal audit, but the difference is not obvious. To a certain extent, the role of internal audit in the performance improvement has not been brought into play, that is, hypothesis two has not been fully verified.

### 3.4. The analysis of the second module

Detailed performance indicators of internal audit refer to the profitability of a company, the profit margin of the assets, the net profit margin and the net profit margin. Most of the operating indicators are the asset-liability ratio, operating cash flow, the total assets of the internal audit department of corporate PV lighting and the main business income ratio. There will be a higher debt ratio of cash flow. The asset liability ratio of PV lighting enterprise that takes the leading mode of the board of supervisors will be relatively high. In terms of capital management, the leadership mode of CFO has the best performance, while the performance of enterprises in the leading mode of the board of supervisors is poor. This situation requires a large number of data testing, and the test results are shown in Table 3.

## 4. RESULTS ANALYSIS AND DISCUSSION

Through the study of the data above, we can draw the following conclusions: firstly, in each sample of enterprises, enterprises with internal audits are larger in size than those without internal audits. Enterprises with large scale are more inclined to implement the board leadership mode, supervisor leadership mode and general manager leadership mode. Small enterprises are often more inclined to carry out the leadership mode of financial department and CFO leadership mode. Secondly, in the photovoltaic lighting enterprises, the performance of enterprises that set up internal audits is more stable, but the performance of those without internal auditing is noticeably deteriorating, suggesting that enterprises that set up internal audit maintain the survival of enterprises. The stability of enterprise performance has played an important role, that is, the protective role of internal audit makes the performance of enterprises better. Thirdly, in the enterprises with different audit modes, their performances are also different: Enterprises that use CFO leadership mode pay more attention to the management of funds. Enterprises that use supervisor leadership mode pay more attention to the management of credit. The internal debt ratio is high, and there is poor management of funds, but the return on net assets is on the rise. Fig. 1 shows the internal audit model under the leadership of the board of supervisors in the lighting enterprises after the application of the growth rate of corporate income comparison. The X axis is the annual dimension coordinate with the start year of 0, and the Y axis is the ratio of the corresponding year's growth. As you can see from the graph, the yield is generally on the rise, with a slight increase in growth. The audit model is positively related to the impact of corporate net asset yield. No significant differences in the performance of the other three audit modes can be found. The independence of internal audit has no significant effect on the improvement of enterprise performance. Therefore, the security function of internal audit has not been fully developed.

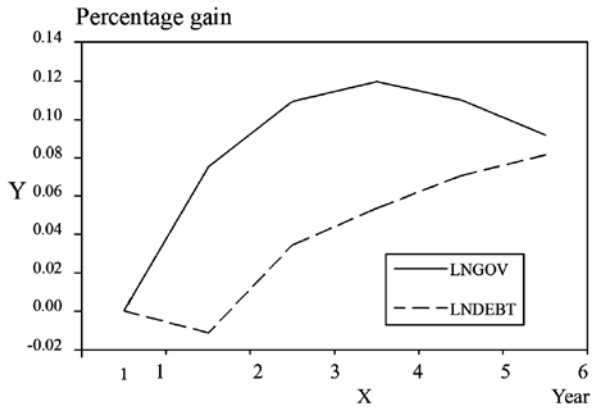


Fig.1. Growth rate of photovoltaic lighting enterprises

For the future development of photovoltaic lighting enterprises, the following recommendations can be made. Firstly, it is necessary to constantly improve the internal audit system, clarify the functions and authority of the internal audit, and play the functions of the internal audit of the enterprise. The majority of the roles of the internal audit department of photovoltaic lighting enterprises still remain in the enterprises' prevention and organization feedback. Through the enterprise's internal audit department, the importance of the enterprise has not been fully displayed.

Of course, there are limitations in the research process. Firstly, the classification of photovoltaic lighting listed enterprises is not specific, which needs to further explore the classification. Secondly, the actual operation of different internal audit departments can't be fully observed. For example, in the leadership mode of the board of directors, the internal audit enterprise is likely to be controlled by the president, but it is possible that both the president and general manager will be delegated by the shareholders. In such case, it is difficult to calculate and evaluate the efficiency of audit mode. Thirdly, the role played by internal audits in improving enterprise performance can't be accurately judged in the short term, which takes time to analyze.

## 5. CONCLUSIONS

Through the empirical analysis of the internal audit of China's photovoltaic lighting enterprises, a lot of information and data were obtained. In making the hypothesis of the data the data of the internal audit department need to be constantly updated and researched, the functions and authority of the internal audit need to be clearly defined, and the very function of the internal audit of the enterprise needs to be played. In order to improve the competitiveness of enterprises in the economic market, the methods of empirical analysis and hypothesis theory were used, and a series of conclusions were drawn, as is shown below. The majority of the roles of the internal audit departments of photovoltaic lighting enterprises remain in the enterprise's prevention and organization feedback, and the importance of the enterprise has not been fully displayed through the enterprise's internal audit department. As for the problems and difficulties mentioned above, some solutions were put forward. The internal audit department of listed enterprises of photovoltaic lighting needs to learn to adapt to the environmental changes in the market economy, and develop the corresponding areas of auditing service, based on which, the management audit can be carried out with the goal of internal governance, so as to improve the performance of photovoltaic lighting enterprises.

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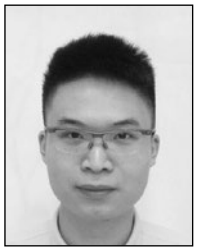

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# EVALUATION OF FINANCING EFFICIENCY OF LISTED COMPANIES IN PHOTOVOLTAIC INDUSTRY BASED ON DEA MODEL

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## ABSTRACT

As a high-tech industry, photovoltaic industry maintains a high growth rate, which greatly promotes the rapid development of traditional and emerging industries in China. The photovoltaic industry also brings the positive influence to the development of economy and innovation of technology. But in recent years, the financing problem of photovoltaic industry has become a bottleneck that restricts the sustainable development of the enterprises. Based on Data Envelopment Analysis (DEA), this paper selects 21 listed companies in LED lighting industry in China to evaluate the financing efficiency from 2013 to 2015. The results are as follows:

– The financing efficiency of listed companies in LED lighting industry as a whole is on the rise, but it is still at a low level;

– The financing efficiency of listed companies is uneven and the difference is significantly different;

– The scale efficiency is relatively high and the proportion of enterprises in the state of decreasing returns to scale is gradually rising.

For this trend, enterprises should further increase investment to realize economies of scale. For non-DEA efficient samples, this paper puts forward the countermeasures to improve the financing efficiency of listed companies in LED lighting industry. That is, the listed companies should focus on adjusting the total assets, reducing the main business costs and improving its profitability and growth ability.

**Keywords:** photovoltaic industry, LED lighting industry, financing efficiency, DEA model

## 1. INTRODUCTION

Energy is an important foundation for social development and national economy. There is a strong correlation between energy consumption and economic growth [1]. In order to promote the diversified and sustainable development of energy, the utilization of photovoltaic becomes an important breakthrough of the new energy. In the context of the rapid development of the global optoelectronic market, the application of photovoltaic industry is becoming more and more extensive, and the market value is growing rapidly, which plays an important role in improving economic and operating efficiency. China's photovoltaic industry in many directions and fields is close to the international leading level. The virtual power plant realizes a new crossing and the integration of the distributed energy resources [2]. The optical market has a lot of room for development which creates a new profit growth point for economic development. However, China's photovoltaic industry has not yet formed the scale effect. Problems such as backward technology level, imbalanced regional development and other issues restrict the further development of the industry. The contradiction of capital demand and supply of the

enterprise is increasingly prominent. Therefore, evaluating the financing efficiency of listed companies in photovoltaic industry and putting forward effective countermeasures will help to improve the profitability and market competitiveness, realize the maximization of the value and promote the sustainable development of the photovoltaic industry.

As for enterprises' financing efficiency, domestic and foreign scholars have conducted in-depth discussion and have received a lot of research results. But for the photoelectric industry's financing efficiency, the research is extremely limited. Don Charles et al. took research on the characteristics of the photovoltaic industry. They pointed out that the existence of information asymmetry and high cost of pre-investment led to the financing difficulties in the photovoltaic industry, and the financing environment needed to be improved [3]. Zeng Ming et al. took the PV industry as the research object and pointed out that the financing channel of the PV industry was single and the contradiction between the enterprise's capital shortage and the blind investment was increasingly sharp. The result indicated the innovative financing model could effectively improve the financing efficiency [4]. Gao Wei pointed out that the domestic development of the photovoltaic industry is trapped in the position of financing difficulty. The financial support for the sustainable development of this industry was insufficient and enterprises needed to explore new financing models [5]. Sanderson et al. selected the DEA method to evaluate the scale efficiency and the pure technology efficiency of listed companies in LED lighting industry. The result showed that the scale efficiency was better than the pure technology efficiency [6]. Zhu Zhenhong studied the financing problems of the photovoltaic industry and pointed out that the financing difficulty was the key factor that restricted the development of this industry. Through introducing the co-financing model the funding demand of enterprise could be effectively meet [7]. Chuanhui Liao , Yunhao Zhu et al. researched the financing issues from the perspective of internal and external social capital. They pointed out that the different social capital had different effect on the financing performance [8]. Zou Zongfeng et al. studied the financing ecosystem of LED industry based on data pledge. He pointed out that measures should be taken to reduce the asymmetry of information and the financing cost so as to improve the efficiency of capital allocation [9].

In view of the existing literature rarely evaluate the input-output efficiency of the photovoltaic industry, this paper selects LED lighting industry as research objective to analyze its financing efficiency through DEA method. This paper also puts forward the countermeasures to improve the financing efficiency of listed companies in LED lighting industry so as to provide practical guidance and reference for improving the financing efficiency of photovoltaic industry in China.

## 2. MODEL DESIGN

### 2.1. DEA model of financing efficiency

This paper uses the DEA model which is proposed by Charnes, Cooper and Rhodes in 1978 to evaluate the financing efficiency of listed companies in LED lighting industry. The DEA model mainly includes three types: CCR, BCC and NIRS, which can be used to measure different efficiency. The weight of input and output variables in DEA model is calculated from the mathematical programming according to the data, which can effectively avoid the influence of the subjective factors, reduce the errors and evaluate the relative effectiveness of the similar multi-input and multi-output of decision-making units. The DEA model is a relatively mature and effective analysis tool. The method hypothesizes that each decision-making unit is on behalf of a listed company, if there are $n$ decision-making units in photovoltaic industry (DMUj, j = 1, 2 …, n), then the $i^{th}$ input and the $r^{th}$ output of the $j_o{}^{th}$ decision-making unit are respectively $x_{ijo}$ and $y_{ijo}$. The CCR (constant returns to scale) model is:

$$\begin{cases} \min[\theta - \varepsilon(\sum_{i=1}^{m} s_i^{-} + \sum_{r=1}^{s} s_r^{+})] \\ s.t. \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^{-} = \theta x_{ij0}, i \in (1,2,...m) \\ \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^{+} = \theta y_{rj0}, r \in (1,2,...s) \\ \theta, \lambda_j, s_i^{-} s_r^{+} \geq 0, j = 1,2,...n \end{cases} \quad (1)$$

Among them, $\varepsilon$ is the infinitesimal of non-Archimedes; $s^+$ is the slack variable of input; $s^-$ is the slack variable of output; $m$ is the number of input

variables; $n$ is the number of output variables. The efficiency value based on CCR model is technical efficiency of listed companies in photovoltaic industry. If the value is higher, the efficiency of capital investment is better.

But CCR model ignores the scale of the enterprise. Considering the scale of listed companies in photovoltaic industry is significantly different and not all of the companies can run under the ideal scale, it's necessary to introduce the BCC (variable return to scale) model, which can be used to remove the influence of scale efficiency. By adding the constraint condition $\sum_{j=1}^{n}\lambda_j = 1$ in model (1), it can receive the BCC model to get the pure technical efficiency (PTE$j_0$) of the $j_0^{th}$ decision-making unit. The BCC model is:

$$\begin{cases} \min[\theta - \varepsilon(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+)] \\ s.t. \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta x_{ij0}, i \in (1,2,...m) \\ \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = \theta y_{rj0}, r \in (1,2,...s) \\ \sum_{j=1}^{n} \lambda_i = 1 \\ \theta, \lambda_j, s_i^- s_r^+ \geq 0, j = 1,2,...n \end{cases} \quad (2)$$

The meaning of each variable is the same as the above. According to TE$j_0$/PTE$j_0$, it can get the scale efficiency (SE$j_0$) of the enterprise. When $\theta$=1, $s^+$ or $s^-$=0, DMU$j_0$ is DEA efficient. The decision-making unit achieves constant return to scale and the best technical efficiency when $\theta$=1, $s^+$ or $s^-$>0, DMU$j_0$ is weak DEA efficient; when $\theta$<1, $s^+\neq 0$, $s^-\neq 0$, DEA$j_0$ is invalid.

### 2.2. Sample selection and variable design

As for the classification of the photovoltaic industry, the current academia and industry has not yet formed a unified conclusion. Therefore, this paper takes the representative sample – LED lighting industry – as the research object. In order to better reflect the development and change trend of financing efficiency of this industry, this paper selects the corporate annual report data disclosed by Wande Database from 2013 to 2015. In addition, this paper excludes the ST companies whose financial status is abnormal and companies without data, and eventually selects 21 listed companies in LED lighting industry in China. Since the DEA model requires that the number of samples must be more than twice of the sum of the input and output variables, so the sample quantity conforms to the requirements of the rule of thumb.

Complying with the principles of importance, comparability and comprehensiveness, this paper also adopts the availability of data and characteristics of LED lighting industry. It finally chooses three input variables and three output variables. The three input variables are total assets, asset-liability ratio and main business costs. The total assets reflect the enterprise's operating size and its financing scale. The asset-liability ratio reflects the rationality of enterprise's capital structure. The main business costs reflect the enterprise's profit and its assets utilization ability. The three output variables are return on equity, total assets turnover and growth rate of the main business income, which respectively reflect the profitability, operational capacity and growth ability of the enterprise. The evaluation index system is shown in Table 1.

Despite there are other input and output variables that measure the financing efficiency, the selected in this paper variables can fully reflect the input and output conditions of funds of listed companies in LED lighting industry.

## 3. EMPIRICAL ANALYSIS

### 3.1. Evaluation result of financing efficiency

The input and output variables in DEA model must be positive, but the original data of input and output variables may be negative. So it is necessary to introduce dimensionless method to deal with the input and output data. The specific method is:

$$y_{ij} = 0.1 + \frac{x_{ij} - m_j}{M_j - m_j} * 0.9. \quad (3)$$

Among them, $m_j$= min ($x_{ij}$), $m_j$ = Max ($x_{ij}$), $y$ = [0, 1], $i$ = (1, 2,…n). By using the DEA p.2.1, we can get the evaluation result of financing efficiency of 21 listed companies in LED lighting industry

**Table 1. The evaluation system of financing efficiency of listed companies in LED lighting industry**

| Level | Name | Computing method |
|---|---|---|
| Input Variable (X) | Total Assets (X1) | X1=Total Assets |
| | Asset-Liability Ratio (X2) | X2=Total Liabilities / Total Assets |
| | Main Business Costs (X3) | X3=Main Business Costs |
| Output Variable (Y) | Return on Equity (Y1) | Y1=Net Profit / Average Net Asset *100 % |
| | Total Assets Turnover (Y2) | Y2=Operating Income/Average Total Assets*100 % |
| | Growth Rate of the Main Business Income (Y3) | Y3=(The Current Main Business Income – The Main Business Income of the Previous Period) / The Main Business Income of the Previous Period*100 % |

from 2013 to 2015. The specific results of technical efficiency, pure technical efficiency and scale efficiency from 2013 to 2015 are shown in Table 2, which reflects the whole situation of the financing efficiency of listed companies in LED lighting industry.

The technical efficiency reflects the whole situation of the financing efficiency of listed companies in LED lighting industry. From Table 2, it can be seen that the mean of technical efficiency of 21 listed companies in LED lighting industry from 2013 to 2015 are 0.732, 0.719 and 0.825 respectively. The technical efficiency of different company is uneven. In 2015, for example, the maximum value of technical efficiency is 1, but the minimum value is only 0.178. Pure technical efficiency reflects the capacity of output that an enterprise can obtain in LED lighting industry in the established input condition. The mean of pure technical efficiency of 21 listed companies in LED lighting industry from 2013 to 2015 are 0.801, 0.762 and 0.865 respectively. The pure technical efficiency is still at a low level. Scale efficiency reflects whether the scale of enterprise achieve the optimal level. The means of scale efficiencies of 21 listed companies in LED lighting industry from 2013 to 2015 are 0.905, 0.938 and 0.946 respectively. Although the scale efficiency increases year by year, not all of the samples reach the optimal level. From the further analysis to its change from 2013 to 2015, it can be seen that the financing efficiency of LED lighting industry as a whole is on the rise.

The specific explanations are as follows:

– Among the 21 decision-making units DMU in LED lighting industry, 6 listed companies' technical efficiency are equal to 1 which means that their financing efficiency were DEA efficient in 2013. These DEA efficient companies accounted for 28.6 % of the total sample. In 2014, 6 listed companies' technical efficiency were DEA efficient and account for 28.6 % of the total sample. In 2015, 12 listed companies' technical efficiency were DEA efficient and account for 57.1 % of the total sample. The data indicates the financing efficiency of these companies is relatively effective. Both of their input and output are in the ideal state.

– In the aspect of pure technical efficiency, 10 listed companies' pure technical efficiency is DEA efficient and account for 47.6 % in 2013. 6 listed companies' pure technical efficiency is DEA efficient and account for 28.6 % in 2014. 13 listed companies' pure technical efficiency are DEA efficient and account for 61.9 % in 2015. It can be seen that not all of the companies can reach DEA efficient in technical efficiency and pure technical efficiency at the same time. The reason of non-DEA efficient is that their scale efficiency has not achieved DEA efficient level.

– As for the scale efficiency, 15 listed companies' scale efficiency hasn't reached DEA efficient and account for 71.4 % of the total sample in 2013. 15 listed companies' scale efficiency hasn't reached DEA efficient and account for 71.4 % in 2014. 9 listed companies' scale efficiency hasn't reached DEA efficient and account for 42.9 % in 2015. The data shows that the operating scale of most of the listed companies in LED lighting industry is not optimal, which is closely related to the high requirement of technology and pre-investment costs of photovoltaic industry. Just the adjustment of the

**Table 2. Calculation result of financing efficiency of listed companies in LED lighting industry from 2013 to 2015**

| DMU | 2013 | | | | 2014 | | | | 2015 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Technical Efficiency | Pure Technical Efficiency | Scale Efficiency | Status of Returns to Scale | Technical Efficiency | Pure Technical Efficiency | Scale Efficiency | Status of Returns to Scale | Technical Efficiency | Pure Technical Efficiency | Scale Efficiency | Status of Returns to Scale |
| DMU1 | 0.975 | 1.000 | 0.975 | drs | 0.717 | 0.718 | 0.999 | drs | 0.810 | 0.816 | 0.993 | irs |
| DMU2 | 0.178 | 0.190 | 0.937 | irs | 0.212 | 0.232 | 0.912 | irs | 0.207 | 0.235 | 0.879 | irs |
| DMU3 | 0.495 | 0.755 | 0.656 | irs | 0.594 | 0.752 | 0.790 | irs | 1.000 | 1.000 | 1.000 | - |
| DMU4 | 0.711 | 0.751 | 0.948 | irs | 0.773 | 0.799 | 0.968 | drs | 1.000 | 1.000 | 1.000 | - |
| DMU5 | 0.332 | 0.350 | 0.950 | irs | 0.383 | 0.287 | 0.991 | irs | 0.415 | 0.457 | 0.907 | irs |
| DMU6 | 0.231 | 0.562 | 0.411 | irs | 0.542 | 0.573 | 0.945 | irs | 1.000 | 1.000 | 1.000 | - |
| DMU7 | 0.814 | 0.927 | 0.878 | irs | 0.787 | 0.924 | 0.852 | irs | 1.000 | 1.000 | 1.000 | - |
| DMU8 | 1.000 | 1.000 | 1.000 | - | 1.000 | 1.000 | 1.000 | - | 1.000 | 1.000 | 1.000 | - |
| DMU9 | 0.616 | 0.619 | 0.955 | drs | 0.560 | 0.573 | 0.977 | drs | 0.730 | 0.748 | 0.976 | drs |
| DMU10 | 0.779 | 1.000 | 0.779 | drs | 0.731 | 0.738 | 0.991 | irs | 0.568 | 1.000 | 0.568 | drs |
| DMU11 | 1.000 | 1.000 | 1.000 | - | 1.000 | 1.000 | 1.000 | - | 0.863 | 0.897 | 0.962 | drs |
| DMU12 | 0.616 | 0.849 | 0.725 | irs | 0.971 | 0.973 | 0.998 | drs | 1.000 | 1.000 | 1.000 | - |
| DMU13 | 0.699 | 0.801 | 0.873 | irs | 0.746 | 0.858 | 0.869 | irs | 1.000 | 1.000 | 1.000 | - |
| DMU14 | 1.000 | 1.000 | 1.000 | - | 1.000 | 1.000 | 1.000 | - | 1.000 | 1.000 | 1.000 | - |
| DMU15 | 1.000 | 1.000 | 1.000 | - | 0.661 | 0.766 | 0.862 | irs | 1.000 | 1.000 | 1.000 | - |
| DMU16 | 0.599 | 0.600 | 0.998 | irs | 0.353 | 0.458 | 0.771 | irs | 0.461 | 0.550 | 0.839 | irs |
| DMU17 | 1.000 | 1.000 | 1.000 | - | 1.000 | 1.000 | 1.000 | - | 1.000 | 1.000 | 1.000 | - |
| DMU18 | 0.400 | 0.423 | 0.946 | irs | 0.430 | 0.434 | 0.990 | irs | 0.524 | 0.586 | 0.894 | irs |
| DMU19 | 0.948 | 1.000 | 0.948 | irs | 1.000 | 1.000 | 1.000 | - | 1.000 | 1.000 | 1.000 | - |
| DMU20 | 0.987 | 1.000 | 0.987 | irs | 1.000 | 1.000 | 1.000 | - | 1.000 | 1.000 | 1.000 | - |
| DMU21 | 1.000 | 1.000 | 1.000 | - | 0.642 | 0.814 | 0.788 | irs | 0.750 | 0.877 | 0.856 | irs |
| Mean | 0.732 | 0.801 | 0.905 | —— | 0.719 | 0.762 | 0.938 | —— | 0.825 | 0.865 | 0.946 | —— |

**Table 3. Input and output conditions should be adjusted of listed companies in LED lighting industry from 2013 to 2015**

| Level | Name | 2013 | | 2014 | | 2015 | |
|---|---|---|---|---|---|---|---|
| | | The Number of Companies Need to be Adjusted | Proportion, % | The Number of Companies Need to be Adjusted | Proportion, % | The Number of Companies Need to be Adjusted | Proportion, % |
| Input Variable | Total Assets | 10 | 66.7 | 12 | 80 | 4 | 44.4 |
| | Asset-Liability Ratio | 0 | 0 | 6 | 40 | 1 | 11.1 |
| | Main Business Costs | 4 | 26.7 | 6 | 40 | 4 | 44.4 |
| Output Variable | Return on Equity | 11 | 73.3 | 11 | 73.3 | 4 | 44.4 |
| | Total Assets Turnover | 6 | 40 | 5 | 33.3 | 1 | 11.1 |
| | Growth Rate of the Main Business Income | 5 | 33.3 | 7 | 46.7 | 3 | 33.3 |

operation scale of enterprise can improve its scale efficiency and technical efficiency at the same time and reach the DEA efficient.

– In 15 non-DEA efficient samples in 2013, there are 3 listed companies in the state of decreasing returns to scale (drs), 12 listed companies in the state of increasing returns to scale (irs). Among 15 non DEA efficient samples in 2014, there are 4 listed companies in the state of decreasing returns to scale and 11 listed companies in the state of increasing returns to scale. Among the 9 non DEA efficient samples in 2015, there is only 1 listed company which is in the state of decreasing returns to scale, 8 listed companies in the state of increasing returns to scale. This data indicates that the scale efficiency of listed companies in LED lighting industry transfers from increasing returns to scale to decreasing returns to scale. The enterprises in the state of drs should make an appropriate reduction of capital investment, reduce the management costs and promote optimal allocation of resources. The enterprises in the state of irs should implement intensive production, expand the operation scale and achieve economies of scale.

In order to find out the key factors that lead to the inefficiency of DEA of listed companies in LED lighting industry, it is necessary to make further study of the redundancy of each input and output variable as well as their proportion accounted for the non DEA efficient samples.

It can be seen from Table 3 that the input variables of listed companies in LED lighting industry most need to be adjusted are total assets and main business costs. The variable of total assets is used to reflect the ability of debt paying and risk-taking of the enterprise. From 2013 to 2015, the total assets of more than 40 % of the listed companies are unreasonable. In view of the total assets, one of the key factors of financing efficiency is that the greater the size of the total assets, the greater the ability of debt paying and risk-taking of the enterprises, the more available financing channels in the market. Therefore, the enterprises should maintain a reasonable amount of total assets. Meanwhile, the control of main business costs of the listed companies is unreasonable. In 2013, the main business costs of 26.7 % in LED lighting industry needed to be adjusted. In 2014, 40 % needed to be adjusted. In 2015, 44.4 % needed to be adjusted. The main business costs have an important impact on the efficiency of capital management. The higher the main business costs, the smaller the profit of enterprise; the lower the main business costs, the greater the profits of enterprise. So, the listed companies should further strengthen the control of operating costs through internal control, economies of scale, technical innovation and other ways to improve the efficiency of capital utilization and its management level.

In addition, the output variables most need to be adjusted of listed companies in LED lighting industry are return on equity and growth rate of the main business income. The return on equity reflects the income level of enterprise obtained by production and operation. The more possibilities of variability, the profitability of the enterprise is higher. From 2013 to 2015, the profit ability of more than 40 % of the listed companies was poor. In 2013 and 2014, the return on equity of 73.3 % in LED lighting industry needed to be adjusted. In 2015, 44.4 % needed to be adjusted. Enterprises should select the reasonable marketing strategy to further increase their sales revenue. At the same time, enterprises should also reduce the operating costs to get the maximum corporate profits.

For the ability growth, enterprises should strengthen the management of funds; find new investments, or development opportunities through fully excavating the market demand.

## 4. CONCLUSIONS

As one of national strategic emerging industries, the high requirement of technology and the large costs of pre-investment lead to the financing difficulties of the photovoltaic industry, which seriously affect the sustainable development of the industry. The financing efficiency of photovoltaic industry gradually becomes the focus of attention from all walks of life. This paper chooses total assets, asset-liability ratio and main business costs as the input variables to respectively reflect enterprise's scale, capital structure and utilization ability of assets, selects return on equity, total assets turnover and growth rate of the main business income as the output variables to reflect enterprise's profitability, operational capacity and growth ability respectively. Then this paper adopts the DEA model to evaluate the financing efficiency of the listed companies in LED lighting industry, which is a representative sample of photovoltaic industry. The basic conclusions are as follows:

– Means of technical efficiency of the listed companies in LED lighting industry from 2013 to 2015 were 0.732, 0.719 and 0.825 respectively. Seen from the change trend of technical efficiency, the financing efficiency of LED lighting industry as a whole is on the rise in recent years. But seen from the number of DEA efficient, the samples of DEA efficient are still few.

– Means of pure technical efficiency of the listed companies in LED lighting industry from 2013 to 2015 are 0.801, 0.762 and 0.865 respectively. Although a small drop in 2015, it shows a trend of rising on the whole. Mean of scale efficiency of the listed companies in LED lighting industry from 2013 to 2015 are 0.905, 0.938 and 0.946 respectively. The efficiency level of different enterprise is uneven and the difference is notably different.

– The proportion of listed companies in the state of decreasing returns to scale accounted for the non-DEA efficient samples increases from 20 % to 33.3 % during 2013 to 2015. The scale efficiency of listed companies in LED lighting industry is relatively high, and it gradually transfers from the state of irs to the state of drs. The scale efficiency of different enterprises is not very different.

– The level of financing efficiency of listed companies in LED lighting industry is closely related to the input and output variables. According to the results of empirical analysis, total assets and main business costs are the most need to be adjusted input variables for listed companies in LED lighting industry. Meanwhile, return on equity and growth rate of the main business income are the most need to be adjusted output variables.

In general, as a high-tech industry, LED lighting industry requires a high demand of financing efficiency and technology. Enterprises should focus on maintaining a reasonable amount of total assets, reducing the main business costs, improving the profitability and growth ability to realize the great improve of financing efficiency in the future development.

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# EFFECT MECHANISM OF THE RELATIONSHIP AMONG JOB SATISFACTION, ORGANIZATIONAL COMMITMENT AND JOB PERFORMANCE FOR EMPLOYEES IN LED ENTERPRISES

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**ABSTRACT**

The pursuit of performance improvement has been an eternal topic for enterprises in the process of their survival and development. Only by effectively improving the employees' performance can enterprises maintain sustainable development. The comprehensive performance of modern enterprises, which is closely related to the individual performance of employees, will be achieved through the performance of every employee. Therefore, how to improve staff performance and ignite their engine of enthusiasm has become the focus of discussion between academia and business management circles. In this study, by taking various types of employees as the object of study, the author constructs the research model, which takes the staff satisfaction as an independent variable, the organizational commitment as an intermediary variable, and the job performance as a dependent variable. Besides, the demonstration experiments on the model are further conducted, and the specific data is used to illustrate the feasibility and advancement of the model.

***Keywords:*** employee satisfaction; organizational commitment; job performance

## 1. INTRODUCTION

Studies have shown that if the internal customer satisfaction of an enterprise reaches 85 %, the external customer satisfaction of the enterprise will be increased to 95 %, from which we can see that the improvement of employee satisfaction within the enterprise will bring direct profits for the enterprise. Customer satisfaction can bring good results for the enterprise. Besides, studies also prove that the main influential factor of customer satisfaction is satisfactory service and products provided by employees, so the internal staff satisfaction can bring better services and products for enterprises, which indicates that employees' personal performance also has a crucial impact on corporate performance [1].The life span of an enterprise can't be predicted in advance, and there're a few enterprises with hundreds of years around the world. However, people life is limited. With the emergence of the new generation of practitioners who are more willing to experience multiple lives, companies also hope that employees can contribute their energy to enterprises within the most prosperous, creative and professional value period in their limited professional working hours [2]. The empirical studies show that employee satisfaction has a significant positive effect on task performance and contextual performance. As ante-dependent variable that affects the job performance, the employee satisfaction has an impact on employee performance and contextual performance; the employee satisfaction will enable employees to have a positive attitude and behaviour, enhance the subjective initiative of the staff, thus

improving work efficiency. Employees with high job satisfaction will have higher sense of responsibility are more willing to take extra work. Moreover, they will have a certain migration effect on the emotional factors of job satisfaction [3]. Empirical studies indicate that employee satisfaction has a significant positive effect on organizational commitment. In addition, the employee satisfaction is more influenced by external circumstances and working conditions, which is easier to change, while the organizational commitment presents as a more permanent recognition to the organization; the long-term employee satisfaction will enable employees to turn their satisfaction to the organization, thus generating a commitment to the organization [4].The empirical studies find the impact of the intermediary employee satisfaction of organizational commitment on the task performance and contextual performance. Organizational commitment represents employees' attitudes towards the enterprise, which is the embodiment of employees' identity to the goal of the organization, which will play a guiding role in individual behaviour. Furthermore, employees who acknowledge the goal of the organization, they will work with positive attitudes, which not only makes it easier to achieve work goals, but is also conducive to achieving good job performance. Therefore, the organizational commitment will enable employees to have a sense of responsibility to the organization, and employees are more willing to take extra work and work with colleagues in a good atmosphere of harmonious interpersonal relationships, from which we can see that organizational commitment will also affect the staff performance [5].

## 2. STATE OF THE ART

### 2.1. Research on the relationship between employee satisfaction and job performance

The relationship between job satisfaction and job performance exists as a hot topic in organizational behaviour research [6]. There are three different views on the study of the relationship: causality theory, non-causality theory and redefined conceptual theory. As for causality theory in the early stage, scholars generally believe that the job satisfaction leads to high job performance, so job satisfaction and job performance has a one-to-one correspondence relationship. This view also presents itself in three modes: job satisfaction leads to high job performance; job performance produces employee satisfaction; job performance and job satisfaction interact with each other. Since it's difficult to draw a definite conclusion for the study on the causal relationship between employee satisfaction and job performance at the early stage, scholars turn to research the non-causality relationship between the two in the recent non-causality theory, which can be divided into three categories: non-relational theory, intermediary variable theory and adjustment variable theory [7].

The research on employee satisfaction and job performance in China mainly focuses on the relationship between the two and the influencing factors. On the one hand, on the basis of a comprehensive review of job performance and its influencing factors, it can be inferred through the key event method and questionnaire survey that the impact of job satisfaction, organizational commitment and goal orientation on the sub-dimensions of job performance is inconsistent. The higher the job satisfaction is, the better the performance of the staff is. On the other hand, the impact of organizational commitment and goal orientation on the each sub-dimension of employee performance is not consistent, either. Taking the dynamic model of job satisfaction as a basis, it is proposed that job satisfaction, work behaviour and job performance are relevant, and job satisfaction will affect the employees' work behaviour and exert impacts on organizational performance. Through the empirical research on the family business, it is put forward that the internal satisfaction has a significant impact on the task performance, and the internal and external satisfaction has a significant impact on the contextual performance. Furthermore, it is proposed that the corporate culture of a family business should be built and the employee welfare should be vigorously promoted [8].

### 2.2. Research on the relationship between employee satisfaction and organizational commitment

At present, there is still a controversy over the relation between employee satisfaction and organizational commitment. The controversy mainly lies in three aspects: employee satisfaction affects organizational commitment; organizational commitment affects employee satisfaction; there is only a correlation between the two.

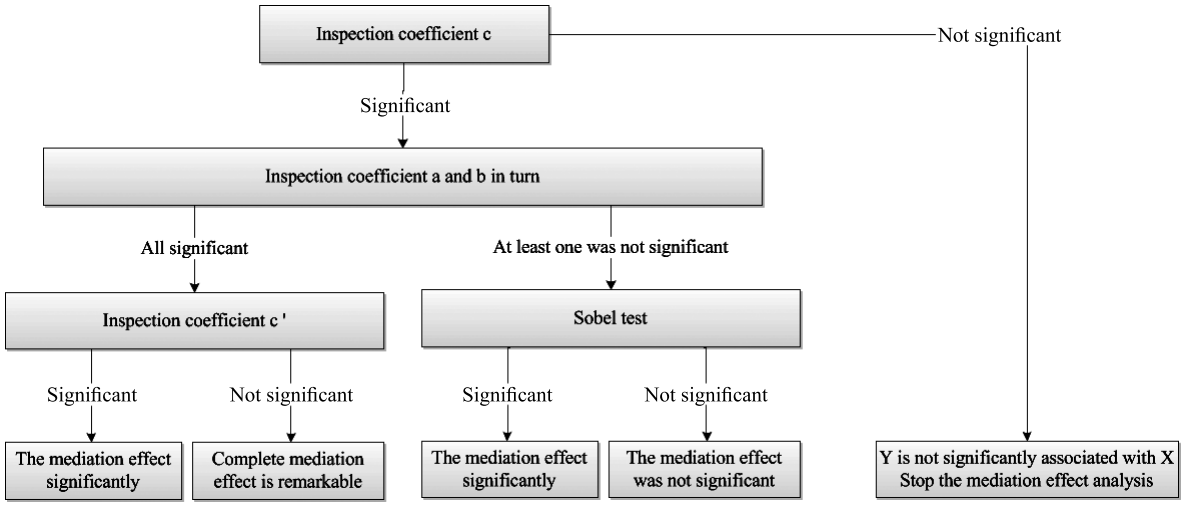


Fig. 1. Mediation test

Compared with job satisfaction, organizational commitment is more stable, which is less affected by situational factors. Job satisfaction is a brief emotional response to a job or within a certain period of time, while organizational commitment is a more persistent assessment response of staff to the organization. From this perspective, job satisfaction is easier to form and is unstable, which can be seen as the antecedent of organizational commitment [9]. A study that takes employees as a sample finds that there's a significant positive correlation between employee satisfaction and organizational commitment, and high employee satisfaction will give rise to high organizational commitment. Therefore, there is a causal relationship between organizational commitment and employee satisfaction, and the organizational commitment is the cause of the formation of employee satisfaction. A few studies believe that after the formation of organizational commitment, employees will spontaneously adjust employee satisfaction to the level that is equivalent to organizational commitment, namely, it's considered that the formation of organizational commitment is prior to employee satisfaction. This assumption also reflects a view in social psychology: after individuals commit themselves to an environment, they will develop the attitude associated with this environment [10].

## 3. METHODOLOGY

### 3.1. Mediation principle

When we consider the effect of the independent variable X on the dependent variable Y and X affects Y by affecting M, then we call M the mediation variable. The verification steps are as follows:

Step 1: the dependent variable Y conducts the regression analysis on the independent variable X, as shown in formula 1.

$$Y = a + b1X. \tag{1}$$

Step 2: The mediation variable M conducts regression analysis on the independent variable X, as shown in formula 2.

$$M = a + b2X. \tag{2}$$

Step 3: The independent variable X and the mediation variable M enter the regression equation at the same time, as shown in formula 3.

$$Y = a + b3X + b4M. \tag{3}$$

There is a relatively simple method for testing the intermediary effect, which is not only able to reduce the first and the second types of error, but also to test part of the intermediary effect. The specific test steps are shown in Fig. 1.

The first step is to test the regression coefficient b1. If it's significant, then we will move to the next step, otherwise we will stop.

The second step is to test coefficients b2, b4 in order. If they are all significant, then M mediates at least part of the impact of X on Y; if there is one that is insignificant, then Sobel test will be carried out. If it's significant, then M intermediary effect is significant, otherwise we will stop the test.

**Table1. Employee satisfaction dimensions definition**

| Dimension | Influencing factor |
|---|---|
| External satisfaction | Work status, job independence, job diversification, team roles, teamwork, work initiative, job judgment, job autonomy, ability to work, leadership style, job achievement, leadership decision, professional ethics, job stability |
| Internal satisfaction | Policy implementation, salary distribution, job promotion, working conditions, interpersonal relationships, rewards |

The third step is to test coefficient b3. If it's not significant, then M completely mediates the impact of X on Y; if it's significant, M partially mediates the effect of X on Y.

### 3.2. Research hypothesis

The mediating effect of organizational commitment on employee satisfaction and task performance: employee satisfaction and organizational commitment are one of the factors that affect the performance of employees; the employee satisfaction will eventually respond to their personal performances and affect employees' task performance and contextual performance [11]. Based on the above analysis, as the mediating variables of employee satisfaction and task performance, organizational commitment has the following the hypotheses:

H1: employee satisfaction has a significant positive impact on task performance;

H2: employee satisfaction has a significant positive impact on organizational commitment;

H3: organizational commitment mediate the effect of employee satisfaction on job performance.

The mediating effect of organizational commitment on employee satisfaction and contextual performance: the study on employee satisfaction, organizational commitment and contextual performance should be comprehensively considered by integrating factors such as cultural background, local conditions, enterprise development and other factors. Based on the aforementioned information, the hypotheses of the mediating effect of organizational commitment on employee satisfaction and contextual performance are proposed as follows:

**Table 2. Work performance dimensionality scale definition**

| Dimension | Influencing factor |
|---|---|
| Task performance | Job performance; job quality; work objectives |
| Relevance performance | Part of loyalty; help others; taking on the job |

H4: employee satisfaction has a significant positive impact on contextual performance;

H5: organizational commitment mediates the impact of employee satisfaction on contextual performance.

The mediating effect of organizational commitment on employee satisfaction and job performance: as dependent variables, affective commitment, ideal commitment and normative commitment have certain impact on employee satisfaction and task performance. Based on the impact of employee satisfaction and job performance and the analysis of above-mentioned literature, the meditation hypotheses of organizational commitment types, i.e. affective commitment, ideal commitment, normative commitment and employee satisfaction and task performance are proposed:

H6: employee satisfaction has a significant positive impact on affective commitment;

H7: affective commitment mediates the impact of employee satisfaction on task performance;

H8: employee satisfaction has a significant positive impact on the ideal commitment;

H9: ideal commitment mediates the impact of employee satisfaction on task performance;

H10: employee satisfaction and regulatory commitment have a significant positive impact;

H11: normative commitment mediates the impact of employee satisfaction on task performance.

The mediating effect of organizational commitment on employee satisfaction and contextual performance: contextual performance is a kind of supporting behavioural consequence that actively creates interpersonal atmosphere and working environment to improve task performance. Chinese enterprises, under the unique oriental cultural background, have a strong friendship culture. Once there's a friendship between employees and enterprises, the employees' behaviour will be affected. Based on the impact of employee satisfaction and job performance and the analysis of above-mentioned literature, the meditation hypotheses of orga-

**Table 3. The results of analysis for each scale and various factors reliability**

| Scale | Subscale | Cronbach's Alpha | Taking sufficient Kaiser-Meyer-Olkin metric | Spherical degree test of Bartlett | | |
|---|---|---|---|---|---|---|
| | | | | Approximate chi square | df | Sig. |
| Employee satisfaction | Whole table reliability | 0.92 | 0.90 | 1881.24 | 190.00 | 0.00 |
| | External satisfaction | 0.83 | | | | |
| | Internal satisfaction | 0.90 | | | | |
| Organizational commitment | Whole table reliability | 0.91 | 0.88 | 2434.58 | 300.00 | 0.00 |
| | Affective commitment | 0.90 | | | | |
| | Ideal commitment | 0.86 | | | | |
| | Economic commitment | 0.81 | | | | |
| | Opportunity commitment | 0.70 | | | | |
| Job performance | Whole table reliability | 0.87 | 0.85 | 1004.39 | 66.00 | 0.00 |
| | Task performance | 0.83 | | | | |
| | Associated performance | 0.79 | | | | |

nizational commitment types, i.e. affective commitment, ideal commitment, normative commitment on employee satisfaction and relevance performance are proposed as follows:

H12: the impact of affective commitment intermediary employee satisfaction on contextual performance;

H13: the impact of the ideal commitment intermediary employee satisfaction on contextual performance;

H14: the impact of normative commitment intermediary employee satisfaction on contextual performance.

### 3.3. Scale design

The measurement method of employee satisfaction is to use the Minnesota satisfaction questionnaire short scale. Studies show that: the reliability of satisfaction short scale reaches 0.85–0.91, the reliability of internal satisfaction sub-table is 0.82–0.86, and the reliability of external satisfaction reaches 0.70–0.82; the retest reliability also reaches 0.58. This study will use the Likert 5-point scale to positively score and measure satisfaction.

The definitions of the scale project:

1. External satisfaction: work status, job independence, work diversification, team roles, teamwork, work initiative, job judgment, work autonomy, working ability utilization, leadership styles, work achievements, leadership decision-making, professional ethics, job stability;

2. Internal satisfaction: policy implementation, pay distribution, job promotion, working conditions, interpersonal relationships, incentives, as shown in Table 1.

The organizational commitment scale adopts the organizational commitment scales including five factors such as affective commitment, normative commitment, ideal commitment, opportunity com-

**Table 4. Results of the regression analysis of the mediating role of organizational commitment on employee satisfaction and task performance**

| Analysis step dependent variables | First step task performance | Second step task performance | Third step organizational commitment |
|---|---|---|---|
| Control variable | | | |
| Job | 0.00 | -0.02 | 0.10 |
| Industry | 0.02 | 0.05 | -0.14 |
| Enterprise nature | -0.05 | -0.03 | -0.10 |
| Independent variable | | | |
| Degree of satisfaction | 0.35** | 0.25** | 0.42** |
| Organizational commitment | | 0.25** | |
| R square | 0.26 | 0.30 | 0.40 |
| Modified R square | 0.16 | 0.191 | 0.31 |
| F | 2.56** | 2.84** | 4.71** |

mitment and economic commitment, and uses Likert's 5-point scale to measure the scores.

The work performance scale adopts the two-dimensional model of task performance-peripheral performance, and the item-settings in the two-dimensional model of task performance-peripheral performance mainly consults the definition of task performance, which consists of three aspects: job performance, work quality and working goal. The contextual performance refers to the dimensions of contextual performance, which consists of three sub-dimensions: partial loyalty, helping others, and taking on extra job. Specific definitions are shown in Table 2.

SPSS software is used to analyze the reliability and validity of the whole table and the subscales of employee satisfaction, organizational commitment scale and employee job performance scale. The results are shown in Table 3.

## 4. RESULTS ANALYSIS AND DISCUSSION

### 4.1. The regression analysis of the mediating role of organizational commitment for employee satisfaction and task performance

The analysis method of the linear regression equation is used to conduct the regression of organizational commitment impact on employee satisfaction and task performance. The results are shown in Table 4.

From the Table 4 it could be seen that for the task performance of dependent variables, the satisfaction ($\beta$=0.35, $p<0.01$) has a significant positive effect on the task performance; the organizational commitment ($\beta = 0.25$, $p <0.05$) has a significant positive effect on task performance. For the dependent variable organizational commitment, the satisfaction ($\beta$=0.42, $p<0.01$) has a significant effect on organizational commitment. The organizational commitment partially exerts its meditating effect on employee satisfaction and task performance. Therefore, hypothesis 1, hypothesis 2, and hypothesis 3 are validated, and the partial mediating effect of organizational commitment on employee satisfaction and contextual performance is verified.

### 4.2. The regression analysis of the meditating role of organizational commitment for employee satisfaction and contextual performance

The analysis method of the linear regression equation is used to conduct the regression of organizational commitment impact on employee satisfaction and contextual performance. The results are shown in Table 5.

In the Table 5, we could see that for the dependent variable contextual performance: satisfaction ($\beta = 0.43$, $p <0.01$) has a significant positive impact on the contextual performance; organizatio-

**Table.5 Results of the regression analysis of the meditating role of organizational commitment on employee satisfaction and contextual performance**

| Analysis step dependent variable | First step associated performance | Second step Associated performance | Third step organizational commitment |
|---|---|---|---|
| Control variable | | | |
| Job | 0.08 | 0.07 | 0.06 |
| Industry | 0.01 | 0.01 | 0.01 |
| Enterprise nature | 0.06 | 0.06 | 0.05 |
| Independent variable | | | |
| Degree of satisfaction | 0.43** | 0.3** | 0.42** |
| Organizational commitment | | 0.37** | |
| R square | 0.3 | 0.37 | 0.40 |
| Modified R square | 0.21 | 0.27 | 0.31 |
| F | 3.13** | 3.87** | 4.71** |

nal commitment ($\beta = 0.37$, $p < 0.01$) has a significant positive impact on the contextual performance. For the dependent variable organizational commitment, satisfaction ($\beta = 0.44$, $p < 0.01$) has a significant positive impact on the contextual performance, the organizational commitment plays a part of the mediating role between employee satisfaction and relevance performance. Therefore, hypothesis 4, hypothesis 5 are verified, and the partial mediating effect of organizational commitment on employee satisfaction and contextual performance is validated.

In summary, after verification, the relationship between employee satisfaction and task performance, and the relationship between employee satisfaction and relevant performance are clear. It's proved that there's a significant positive effect on employee satisfaction and job performance; meanwhile, the employee satisfaction also has a significant positive effect on contextual performance.

## 5. CONCLUSIONS

It has been the problem for business managers and theoretical scholars to ponder on how to keep the core talents of the enterprise, better improve the work performance of the core staff, and thus improve the overall performance of the enterprise. The purpose of this study is to discuss the relationship among employee satisfaction, organizational commitment and job performance. Through the establishment of the model and the results of data analysis, the management recommendations for improving corporate performance are provided for enterprises.

The conclusions of this paper are as follows: on the demographic variables, employee satisfaction, organizational commitment and job performance have significant differences: the employee satisfaction, organizational commitment and job performance show a positive correlation relationship; employee satisfaction has a significant positive predictive effect on organizational commitment, emotional commitment, normative commitment, ideal commitment, economic commitment, opportunity commitment; and the employee satisfaction has a significant positive predictive effect on job performance, task performance, contextual performance; and the affective commitment, normative commitment, ideal commitment have a significant positive predictive effect on job performance, task performance and contextual performance. Besides, the affective and normative commitments are playing a significant mediating role between employee satisfaction and job performance, task performance and contextual performance.

Although this study obtained some valuable results on the basis of empirical research, there're still some shortcomings in the limitation of constraining factors. In the aspect of research object, the research selects enterprises, including state-owned enterprises, private enterprises and joint-stock enterprises as the research objects. Although the scope of data col-

lection is wide, it's inevitable that the data falls short of pertinence. As for various types of data obtained by enterprises, their applicability also needs to be further analyzed when being applied to a certain type of enterprise.

**ACKNOWLEDGEMENT**

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# RESEARCH ON THE DESKTOP CLOUD SECURITY ACCESS AND SHARING MECHANISM OF LED ENTERPRISES BASED ON VIRTUAL ORGANIZATIONS

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***ABSTRACT***

As an emerging industry, the LED industry is still in its initial stage of development, and its conspicuous problems of poor confidentiality of the information system and imperfect safeguard measures, leading to the drain of technical information and hindering the development of enterprises. In order to solve the problem of information security access and sharing mechanism in LED industry under cloud services, the thesis proposes the protection model of small user sharing of cloud security, and compares such attributes as encryption, decryption and revocation of the secure access mechanism of LED industry with other programs, through the study of improbable secure access model from the perspective of cloud security sharing, finding that the secure access mechanism of the information system of the LED industry is with strong security, high efficiency and high accuracy; the information sharing mechanism is with strong security, fast computing speed and privacy. From the cloud security, the encryption of content in the mechanism, the realization of anonymous evaluation, the susceptibility and unnecessary re-encryption save the computing time and cost. The model built in the thesis is secure in both the information security access and sharing of the LED industry, has advantages in application and lays a theoretical foundation for practical application.

***Keywords:*** cloud service, LED industry, improbable security access mechanism, sharing protection mechanism of small users, sharing protection mechanism of large users

## 1. INTRODUCTION

With the rapid development of information technology, great changes have taken place in the world economy, and the LED industry has become a sunrise industry with great popularity. In particular, the LED industry featured with high efficiency and environmental protection has a broad market prospect, ideal potential for development and good effect of energy conservation and emission reduction. LED is the abbreviation of light-emitting diode, a semiconductor electronic component. Composed of type *p* conductors and type *n* conductors, it converts electric energy into light energy, giving out luminescence spontaneous radiation. With the continuous development of the industry, breakthroughs in technology and vigorous promotion of the application, the luminous efficiency of LED is also constantly improving. At present, the LED industry has gradually entered the city lighting, display screen, traffic signals, advertising and automobile lights and other fields [1]. In the near future, LED will become the mainstream light source of the lighting industry. However, for a long time, the LED industry in China has relied on such forms of processing trade as accepting customers' materials for processing, processing with supplied samples and compensation trade, which makes implementations accor-

ding to other people's idea, lacks of independent brand and still has some uncertainties in technology. As the emerging industry of green light sources, the LED industry is able to make rational use of the cloud computing technology and independent technology of research and development to realize the secure access and sharing of the information content and ensure the security and validation of the information, and becomes the first task in the development of the LED enterprises under the background of poor security and products and a lack of independent innovation [2].

The security access mechanism under the cloud services is a very complicated problem, and the problem cannot be solved fundamentally by a single technology or from a single aspect. From the perspective of the data owner, the control technology of the secure access to cloud services is attributed to the secure access control of data. At present, the main existing technologies are data encryption technology, probable cloud computing technology, authentication technology and security enhancement technology, which are applied to the services and data security and to sharing of cloud services under the condition of cloud services, and push forward the progress of cloud services applications. Now, there is little research on the security access mechanism in China. Some scholars pointed out that the encryption technology is an effective means to protect data confidentiality, because under cloud services, if the user encrypts the data, the provider cannot obtain the user data. Experts concerned pointed out the new double encryption method, which combines with the layer number of the secret key to induce users to decrypt the key, in order to the number of users' secret keys. Yang Liu et al designed an access control model CARBAC under the cloud computing, put forward the lookup algorithm of the role of user permission in the environment of cloud computing, and assigned the select quantity of the algorithm to users. Huang Jingjing et al put forward the cloud computing access control model based on the context in the environment of cloud computing, introducing the customer attributes, and granting users rights based on the context information and constraints. On the contrary, foreign countries have made much contribution to the research of secure access mechanism. Shamir et al proposed a secret sharing scheme, making use of the polynomial to process the secret key with the user attribute, to resist the multi-user collusion attacks.

Shamir believes that the user secret keys are randomly generated through different polynomials, enabling different user keys to be independent of each other and choosing the security model under the assumption that DBDH is difficult. Vipul Goyal et al divide the attribute base-cryptography into two broad categories: attribute-based encryption of cipher text policy (CP-ABE) as well as attribute-based encryption of secret key policy (KP-ABE). The access control was first proposed in their thesis, realizing the encryption scheme of secret key attribute under the security model. Vincent W.S. Wong and others proposed the structure scheme of hierarchical access control, combing the hierarchical thinking with the tree hierarchy to improve the efficiency of attribute-base encryption [3].

In summary, with the rapid development of cloud services, the research of cloud service security has also achieved a series of major research results; for example, it has made more achievements in the access control technology of attribute encryption and the cipher text computing of homomorphic encryption technology. However, there are still a lot of problems to be solved in the access control of cloud services, and some of the existing research results cannot be satisfactory in practical applications, which hinders the large-scale application and promotion of cloud services technology in various industries.

## 2. RESEARCH METHODS

In the research of the improbable secure access and sharing mechanism of cloud services, in order to improve the security and confidentiality of the information system of the LED industry, the research of the secure access and sharing of the platform of data information is made. The thesis ensures the confidentiality of the original technology of the information platform of the LED industry through the study of improbable cloud security access and sharing mechanism, which is of great significance to promote the large-scale application of cloud services, and provides new theoretical thinking and basis for the design and development of the combination of cloud services and cloud computing. The system technology of the traditional information platform of the LED industry is still in its initial stage, in the environment of poor openness and confidentiality; the innovative technological means are always imitated, and are difficult to solve the

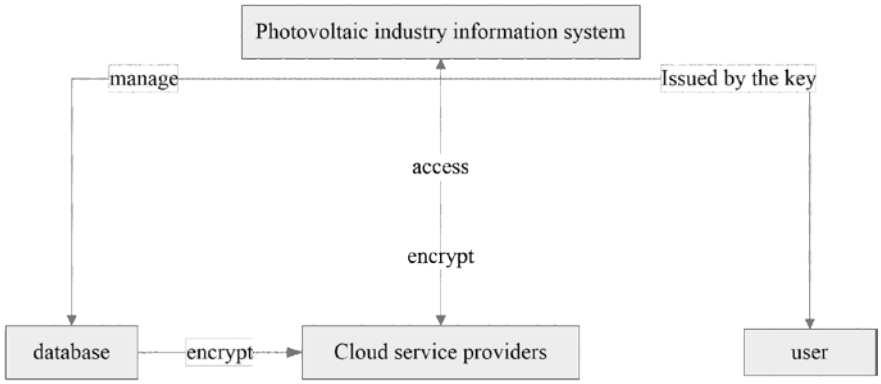


Fig. 1. Photovoltaic information system model

problem of homogenization of products [4]. The LED cloud platform proposes important means and measures to protect cloud access and data sharing through the environment created by cloud computing by using a model with high security and high confidentiality secrecy in such a background [5].

### 2.1. Model of secure access

When a separate key is not trusted, the organization is attacked or invaded [6]. In order to solve the problem of information access security in LED industry, the thesis builds the secure access model in the improbable environment on the basis of the security access mechanism of enterprise level.

The model is implemented on the basis of relevant mathematical theories. The computer achieves the access to the operation of the algorithm through a series of algorithms and models [7]. The basic theory is as follows:

If there are n+ 1 values $\left(x, f\ \ x_m\right)\big)$ the algorithm of Lagrange polynomial interpolation:

$$\mathrm{f}\left(x\right)=\sum_{m=1}^{n} f\left(x_m\right)\left(\prod_{1\le j\ne m\le n}\frac{\left(x-x_j\right)}{\left(x_k-x_j\right)}\right), \tag{1}$$

where the Lagrange coefficient is expressed as:

$$\Delta_{m,j}\ \ x\big)=\prod_{m\in g,m\ne k}\frac{x-k}{m-k}. \tag{2}$$

After the real number x and the real number y are calculated, the information system of the LED enterprise gets the real number *a*, equal to $a=\sum_{k=1}^{p}\left(x_k y-q_k\right)=xy-\sum_{k=1}^{p}q_k$ . The cloud service provider gets the real number b equal to $b=\sum_{k=1}^{p}q_k$, and it makes sense that

$$a+b=xy. \tag{3}$$

When the integer *P* is commonly agreed by the LED industry systems and cloud services providers, the square value of the power of the computer system cannot be normally calculated. At this point, the real number generated by the information system meets $x=\sum_{k=1}^{p}x_k$ .

Send the secret key *J* generated by the system to the provider.

If there are *X* secret data *A* in the system, and the provider gets one of the *X* data, with *m* being equal to 1 and 2, the cloud service provider calculates $H_m y-q_k$ and the result of the information system of $H_j y-q_k$.

Assuming that the information system of the LED industry and its cloud service providers are not entirely credible, users and databases themselves are encrypted and will not disclose information [8].

In Fig.1, the information systems of the photovoltaic industry and database are closely related to users and providers. The system generates and distributes attribute keys. The provider generates and updates the new key cipher text. The database completes the work of data sharing and access strategy.

The Common parameters include the Meta *e*, and the bilinear group *E* consisting of *e* and the Hash function *D* mapped to *E* are manifested as $\left\{E_0, e, D\right\}$.

The main key generated by the system and provider produces the genus set of attribute secret keys

by using the multiplication formula based on the mutual security. After getting the attribute set, users calculate and get the complete secret key [9].

$$AJ = \begin{pmatrix} C = AJ_m + AJ_N = e^{(q+\alpha)/\beta}, \\ \forall k \in A : C_j = e^{'} \cdot C(m)^{'}, C_k^{'} = e^{'} \end{pmatrix}. \quad (4)$$

Set the threshold of each data node, and get the cipher text of the node:

$$NR = \begin{pmatrix} R, O = Me(e,e)^{'}, O = H^{'}, \forall y \in Y : N_y = \\ = e^{R,(0)}, O = D(att(y))^{R,(0)} \end{pmatrix}. \quad (5)$$

Assume that there is a leaf node *x*, when *m=att(x),* there exists:

$$Node(NR,\ AJ, x) = F(e,\ e)^{qR_0}. \quad (6)$$

The node represents the decryption function. When *m = att (x),* there exists:

$$Node(NR,\ AJ, x) = \phi. \quad (7)$$

Assume that x is a node other than a leaf node, and *y* is the child node of *X*, there exists:

$$Node(NR,\ AJ, x) = I. \quad (8)$$

When there are $j_x$ sets in $A_x$, there exists

$$I = F(e,e)^{qR(0)}, \quad (9)$$

where *q* is a root node.

Assume that *A* satisfies the access rights of the structure tree, there exists:

$$Node(NR,\ AJ, q) = F(e,e)^{qA}. \quad (10)$$

### 2.2. Protection model of cloud security sharing

Focusing on groups of different numbers of people faced by the different sectors of the LED industry, the thesis makes analyses from the two perspectives of small user and large user.

The additive homomorphic encryption algorithm in the thesis needs to reference the related formula, as is shown in the next equations:


Fig. 2 LED industry mechanism of sharing information system security

$$\varepsilon = En(p, j, B) = p + j(mo \cdot B), \quad (11)$$

where *B* is an integer of greater value.

$$Dec(\varepsilon, j, B) = \varepsilon - j(mo \cdot B). \quad (12)$$

Set $\varepsilon_1 = En(p_1, j_1, B)$ and

$$\varepsilon_2 = En(p_2, j_2, B), \quad (13)$$

where $p_1 + p_2 \in [0, B-1]$.

Send the encryption content of the LED industry to the data information server; provide a public key to the audit centre and the information key to the authorization server. The data information server encrypts the contents for the user, the audit centre provides public and secret keys to the user, and the license server provides a license to the user [10], as is shown in Fig. 2.

The data information provider provides the proxy encryption key *QY* for the authorization server. The key server provides the public and secret keys *LY1* and *AJ1* for the user and *LY2* and *AJ2* for data information providers. Among them, *QY* is:

$$QY = LQE \cdot Key(AT \cdot LY). \quad (14)$$

After the encryption by the public key provided by content providers, the key server sends data to the content provider again. The content key provided by the content provider by decrypting the secret key is:

$$NEY = NBY + HJ. \quad (15)$$

The encrypted content *O* by *NEY* is:

$$O = (SE(B)). \quad (16)$$

The content provider sends the cipher text to the cloud service provider:

$$NR = \left(E, N = En\left(LY, NBY\right)\right). \tag{17}$$

The service provider sends the user request for LED industry information to the server, and after generating the license, the server then sends it to the user. If the content purchased by a user from a service provider is $\nabla$, there exists:

$$\nabla = \left(NIC, UQ, Rg,\ VWA\right), \tag{18}$$

where *NIC* is a license with content identification, *UQ* is the permission for the license, *Rg* is the timestamp of the license, and *VWA* is the autograph for the license.

Generate the main encryption key:

$$C = E\mathrm{n}\left(LY, NBY\right) = LQ \cdot R\mathrm{e}\left(QY,\ N\right). \tag{19}$$

Send request for the secret key:

$$JW = \left(NIC,\ C, RA, YWA\right). \tag{20}$$

The encryption algorithm of the additive homomorphic public key:

$$Y = En\left(LY, NEY\right) = C \oplus En\left(LY, HJ\right). \tag{21}$$

Generate the license:

$$VIN = \left(NIC, Y, UQ, VIA\right). \tag{22}$$

The secret key to the decrypting content:

$$NEY = De\left(AJ, Y\right). \tag{23}$$

Decrypting content:

$$O = AD\mathrm{e}\left(E\right). \tag{24}$$

The sharing protection mechanism of cloud security established in this thesis is unique, non-transferable and private. The uniqueness means that only licensed users have access. The non- transferability means that unauthorized users are not available. Privacy means that only the user knows his identity, and the rest of the service provider has no weights. Thus, the sharing protection mechanism of cloud security of the LED industry has security.

The encryption operation time of the sharing mechanism of cloud security:

$$2t_a + t_s. \tag{25}$$

Permission to encrypting time:

$$5t_a + t_s + 2t_h + t_r, \tag{26}$$

where $t_a$ is the time for non-encryption operation, $t_s$ is the symmetric encryption operation, $t_r$ is the agent encryption operation, and $t_h$ is the model encryption operation.

### 2.3. The contrast between the algorithm and that of Petrlic

The total time of the encryption and decryption for the model content of small users is $(10t_a + t_r)$, while the time of Petrlic is $(8t_r+2t_s+2t_h+ t_r)$. It can be known that in the application of the security sharing mechanism in the LED industry, if the running time is short and the cost is low, the efficiency will be high.

The algorithm for more users is in the following:

The set of the information attributes of the information system of the LED industry is $X = \left(x_1, x_2, x_3, \cdots, x_n\right)$, with the main secret key being *BY* and the public key being *LY*.

The key here refers to the secret key *AJ* of the LED industry, as is expressed:

$$AJ = MBE \cdot \mathrm{Key}\left(BY,\ A\right), \tag{27}$$

where *A* is the combination of attributes assigned to users by the information system.

First, establish the random key *NEY*:

$$NEY = NBY + LY + HJ. \tag{28}$$

In the formula above, *NEY* is the result obtained by summing up the authorized key *LY* and the auxiliary *HJ*. Encrypt the relevant information of the LED industry *O*, and the result is *NR*:

$$NR = SE\mathrm{n}\left(O\right). \tag{29}$$

*NR* is provided to the cloud service provider. The provider makes encryption through the authorized service provider according to the access strategy, and gets *N*:

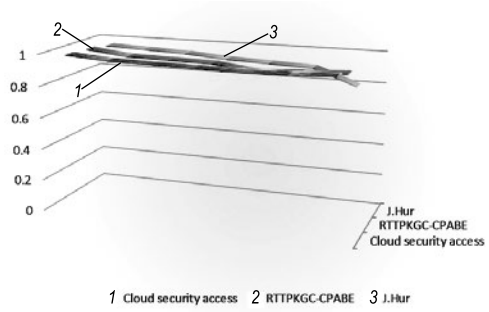


Fig. 3. Encryption, decryption, undo result contrast figure

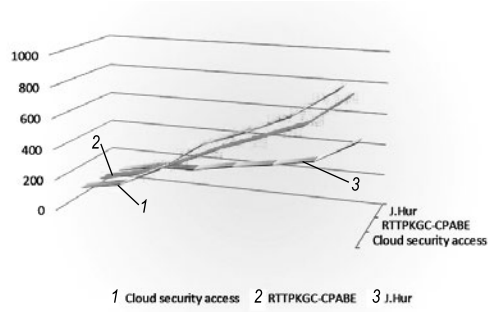


Fig. 4. Success rate result contrast figure

$$N=\begin{pmatrix} N_0 = HB\cdot En\left(LY,HJ\right), N_1 = \\ = En\left(LY,HJ\right) \end{pmatrix}. \quad (30)$$

Finally, make encryption by using the public key, and get:

$$N_2 = En\left(LY,HJ\right). \quad (31)$$

The secret key generated by the user send request for content ordering to the cloud service provider, there exists:

$$NW=\left(NIC,QEX,VHQ=En\left(LY,W\right)\right), \quad (32)$$

where *NIC* represents the information identifier of the LED industry, *QEX* is the permission for the system, *VHQ* represents the authorization request, and *LY* is the public key of the authorized server, and *W* is the information associated with information identifier, permissions, and authorization requests:

$$W=\left(NIC,\ QEX,\ VHQ\right). \quad (33)$$

Generate request VW:

$$VW=\left(VWA=\left(VMW,\ RA\right)\right), Sig\left(AJ,\ VAW\right). \quad (34)$$

Return the license to the cloud service provider, and get

$$VIN=\left(VNN=\begin{pmatrix} VIC,N_0,D_0 = \\ = En\left(\mathrm{QY},\mathrm{DY_s}+\mathrm{DY_K}\right) \end{pmatrix}\right). \quad (35)$$

Finally, hand over the permission to the client-side.

Users send credentials to the secret key server by verifying the validity of *VIN*. The secret key server decrypts it and gets $D=En\left(DY,\ HJ\right)$. The intervention users are using the user's secret key to decrypt it and get $NBY=HB\cdot En\left(AJ,\ N_0\right)$. The user uses the license to decrypt it and get $HY_s+HY_K=De\left(UJ,H_0\right)$. The user uses the algorithm to decrypt it and get $VJ+MY=De\left(HY_s+HY_K,H_1+H_2\right)$. Finally, it decrypts the information and gets $NEY=NBY+LY+HJ$.

If the user's attributes satisfy the access strategy of the re-encrypted cipher text, the decrypted user data according to the homomorphic encryption algorithm are:

$$VIN=\left(VNN=\begin{pmatrix} VIC,N_0,D_0 = \\ = En\left(\mathrm{QY},\mathrm{DY_s}+\mathrm{DY_K}\right) \end{pmatrix}\right). \quad (36)$$

The LED information decrypted can be gained, because $NEY=VBY+LY+HJ$.

## 3. ANALYSES AND DISCUSSION OF THE RESULTS

### 3.1. Security analysis

Through the calculation by the two- party security models and the operation of the simulator, the thesis concludes that the system structure and drilling process of the model involved in the secure access mechanism in the thesis is consistent with the cipher text form and decryption process in the CP-ABE scheme. Therefore, the security in the access mechanism of the cloud security in the thesis is close to that of the access mechanism of CP-ABE. In previous studies, the security of CP-ABE meets the requirements, therefore, the security of the access mechanism of the cloud security also does.

In the experiment, encrypt the access policies with the leave number between 6 and 90, set user

to 5 and the file size to 500 KB. The access mechanism and scheme RTTPKGC–CPABE as well as scheme by J. Hur are analyzed from the perspective of the time for encryption, decryption and revocation as well as the success rate of secure access, and the results are shown in Figs.3 and 4.

As it is shown in Fig. 3, the attributes of the encryption, decryption and revocation of the LED security access mechanism will increase with the increase of the number of information nodes. Compared with other schemes, its increasing trend is even more pronounced. As it shown in Fig. 4, the model has the highest success rate of information processing. Thus it can be seen that the secure access mechanism of the information system of the LED industry has high safety, high efficiency and high accuracy in information processing.

### 3.2. Correctness analysis

The thesis makes analyses through the comparison between experimental schemes, compares the time cost for decryption and encryption with the content size, and calculates the performance for content encryption and decryption according to the number of attributes and the size of the content; as is shown in Fig. 5, when the number of attributes is set to 8, the time cost for content decryption and encryption and the content size are comparble. As is shown in Fig. 6, the content decryption and the number of access strategy attributes are comparable. If there is a linear relationship between the content size as well as attribute quantity of the access policy and the time cost for content encryption and decryption, the time required to encrypt the content of 10M is less than 1s, with the decryption time being less than the encryption time.

From the comparison between Fig. 5 and Fig. 6, it can be known that it is feasible to protect the content through encryption, and it can restrict the content browsing in time and times, and build a sharing mechanism through the additive homomorphic encryption algorithm and secret keys of CP-ABE content, to ensure the security of the content secret key. This scheme protects the anonymity of users and prevents user information from being leaked due to the habitual behaviour.

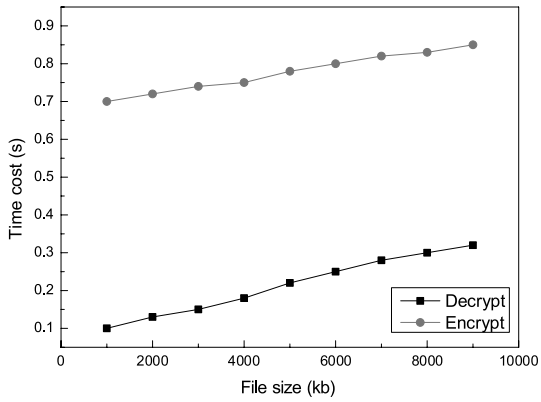


Fig. 5. A chart of the time cost for content decryption and encryption and the content size

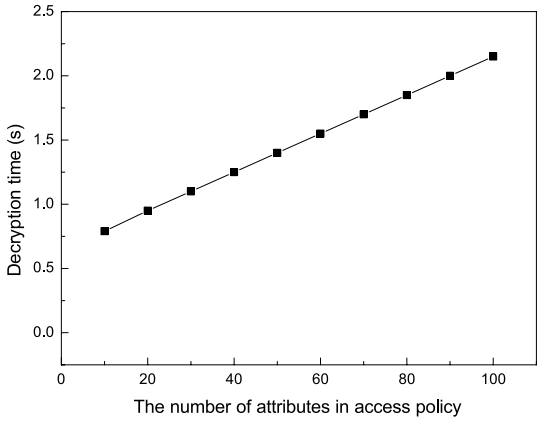


Fig. 6. A chart of the time for encrypting content and the number of access policy attributes

It concludes the following after the comparison between the sharing mechanism of cloud security in the thesis and that of Petrlic, Wang and Muller.

As you can see from Table 1, the sharing mechanism based on cloud security in the research of the LED industry is able to encrypt content, make anonymous comments and be sensitive. In the meanwhile, it doesn't need to re-encrypt, which saves time and cost for calculation. In general, the model presented in this thesis has advantages in the application.

**Table 1. The results of different schemes**

| Plan | Symmetric encryption | Heavy encryption | Anonymous | Sensitive |
|---|---|---|---|---|
| Cloud security access mechanism | Y | N | Y | Y |
| Petrlic | N | Y | Y | Y |
| Wang | Y | N | N | N |
| Muller | Y | N | Y | N |

## 4. CONCLUSION

The emerging LED industry has developed its unique advantages, which play an important role in the development of the whole industry. Both the information system of the LED industry and the cloud service provider are improbable entirely; the user and the database itself are encrypted, and the information will not be leaked. The security of the information system access and information sharing of the LED industry has become the key to the technological innovation development of LED industry. In the thesis, the security of information access and information sharing in the LED industry is studied. The results show that in secure access, after building the model without probable access mechanism, the attributes of the encryption, decryption and revocation of the LED security access mechanism will increase with the increase of the number of information nodes. The model has the highest success rate of information processing. The thesis makes analyses through the comparison between experiment schemes, compares the time cost for decryption and encryption with the content size, and calculates the performance for content encryption and decryption according to the number of attributes and the size of the content, finding that there is a linear relationship among the content size as well as attribute quantity of the access policy and the time cost for content encryption and decryption. It is feasible to protect the content through encryption, and it can restrict the content browsing in time and times, and build a sharing mechanism through the additive homomorphic encryption algorithm and secret keys of CP-ABE content, to ensure the security of the content secret key. Comparing the sharing mechanism of cloud security with that of Petrlic, Wang and Muller, it can encrypt the content, make anonymous evaluations and be sensitive. It doesn't need to have re-encryption, which saves the time and cost for calculation. In general, the security mechanism designed in the thesis has been applied in the LED industry as well as related industries, laying a theoretical foundation for the development of industry.

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# PREVENTION AND MANAGEMENT OF THE CREDIT RISKS OF SOLAR LED ENTERPRISES

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**ABSTRACT**

With the expansion of the issuing scale of the credit bond of Chinese enterprises, the requirement for the credit rating of the bond issuer keeps dropping, and during a predictable period, more incidents of bond default tend to happen. The research aims to adopt the data analysis method to review the development status of solar LED industry in China through the analysis of the current status of the credit risk of solar LED enterprises in China. It finds that after experiencing the blind rapid expansion in the early stage, the solar LED enterprises in China now have showed such unfavourable situations as over-productivity, vicious competition and financing difficulties, which is likely to trigger a wider range of bond defaults and even credit risk. It is believed in the research that solar LED enterprises should deal with these difficulties through such comprehensive means as improving the industrial chain, strengthening capital control and achieving the cross-border integration, gradually build a more transparent corporate bond market, and guide investors to invest more steadily.

***Keywords:*** credit risk, solar LED enterprise, risk prevention, bond

## 1. INTRODUCTION

The basic principle of solar LED automatic lighting system is that, in the case of bright light, solar panels convert light energy into electrical energy, charge the battery and store the energy in the battery. At night, the electric energy in the storage battery charges the semiconductor LED to give illumination effect. With the improvement of the permeability of LED lighting, product prices continue to decline, and in order to gain more profits, LED enterprises have expanded the production line [1,2], intending to achieve the effect of small profits but quick returns through stimulating the demand. Especially the low-end market with the LED industry chain has involved into the severely affected area of over-productivity. After experiencing the rapid expansion in the early stage, LED enterprises in China have now showed such unfavourable situations as over-productivity, vicious competition and financing difficulties. The credit risk and default risk of enterprises are also greatly rising. The bond default of Shanghai Chaori Company in solar LED enterprises happened in 2014 caused a great deal of reaction in the capital market in China. The debenture interest of this company in 2012 reached up to 89 million 800 thousand yuan [3–5]; however, according to the latest announcement issued by the company on 2014, investors could only earn about 4 million yuan of interest income, with the expected income being over 22 times of it. Prior to this, there were no incidents of corporate bond defaults in the Chinese bond market, and most investors regard corporate bonds as a stable, income-guaranteed and highly secure investment channel. It can be said that the credit default incident of the LED enterprise of Shanghai CHAORI Company has given the whole nation a lesson of enterprise credit risks, and

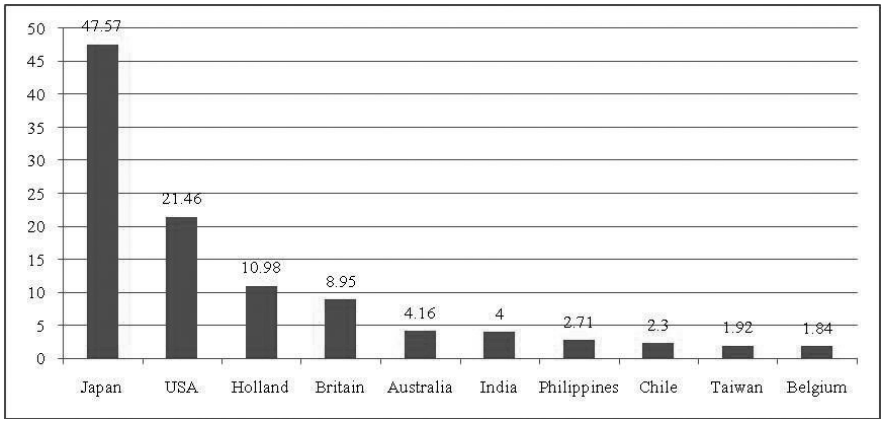


Fig.1. Trade volume ratio of the major export object of the solar energy products in China, (%)

suffered a lot of investors lacking of prevention and management of credit risk [6,7].

The modern financial credit risk includes not only the effect of the changes of the credit level of transaction object and the ability to perform on the value of financial products as well as the risk of causing economic losses to the creditor or holder of financial product, but also the risk loss caused by the decline of the asset price in the investment portfolio. Zhou Hong and other researchers made research and found that the researches on the factors affecting the bond credit risk at home and abroad are mainly based on the internal value of the enterprise, the uncertainty of macroeconomic environment and information asymmetry. Anthony mainly studied the impact of enterprise asset value on the credit risk of the corporate bond. The results show that the fluctuation of assets value is the main reason of credit spreads, and at the same time, the fluctuation level of interest rate is the important factor to determine the credit spread. Bakshi & Madan argues that the company's financial distress indicators include financial leverage, book value and market price ratio, equity volatility and so on [8]. Altman believes that, as the micro subject of the economic activities, the credit risk of the enterprise bonds will inevitably be affected by the macro environment.

In fact, with the expansion of the issuing scale of the credit bond of Chinese enterprises, the requirement for the credit rating of the bond issuer keeps dropping, and during a predictable period more incidents of bond default tend to happen; investors may not only lose interest income [9], but also lose principal in extreme cases. Especially after the bond default of Shanghai Chaori broke the ideal aura of rigid cashing in the public offering bond market, the entire Chinese capital market seemed to have experienced a storm of baptism, behind which a great challenge faced by the entire solar industry with the solar LED industry being a representative, and the increasingly fierce competition in the market are reflected [10]. In this context, it is of very important practical significance to carry out in-depth study on the development status and credit risk assessment.

## 2. RESEARCH METHODS AND FOUNDATIONS

### 2.1. Research methods

**Literature research method:** The research has reviewed all kinds of documents at home and abroad in recent years including monographs, academic papers, periodicals and so on [11], summarized some related research results, realized the liquidity risk of enterprises and the research status of its assessment, and conducted a further research on the impact of asset liquidity risk on solar LED enterprises on the basis of existing studies.

**Case analysis method:** The case analysis method is used in this thesis, and the data analysis and theoretical analysis are adopted in the analysis of the Shanghai CHAORI Solar Technological Incorporate Company, with the default incident, for example, of 11 CHAORI bond being.

**Quantitative analysis method:** The thesis will use the quantitative analysis method in the study, which not only makes quantitative analysis of the various data of the case itself, but also compares them with the relevant data of the market and industry, to deepen the understanding of the problems existing in the case, figure out the relationship, and better grasp the nature of the problem.

### 2.2. Research foundation

Based on the analysis of the development status of solar LED enterprises in China, this study analyzes the factors affecting the credit risk of China's solar LED enterprises, and puts forward some suggestions to prevent the credit risk of solar LED enterprises. At present, the present situation of the development of China's solar LED enterprises mainly shows the characteristics in four aspects.

Firstly, the blind expansion leads to the crisis of overcapacity. The high profits in the solar industry in the past few years caused the number of solar companies in China to increase from dozens in 2008 to more than 600 in 2014, and the blind involvement and expansion of much speculative capital led to a more serious surplus crisis appearing in the solar energy industry in China. In this expansion, the solar LED industry has also become an industry with excess capacity. Although after 2013 some backward capacity have been phased out under the guidance of the national policy and the elimination mechanism of market competition, on the whole, it is still in the situation of overcapacity due to the effect of such unfavourable factors as low level of technology, lack of independent innovation and homogeneous competition.

Secondly, it relies too much on foreign exports. 90 % of the products of Chinese solar energy enterprises are to be exported abroad, and especially western developed countries represented by Europe account for more than 80 % of the share, as is shown in Fig. 1. There is a crisis in such a situation as is too single and heavily dependent on exports. It is a very short-sighted behaviour that for a long time the solar LED industry has been satisfied with the export to large European and American customers ignoring domestic and other international markets. Since 2011, the United States and the European Union have begun the so-called anti-dumping and countervailing investigations on China's solar energy industry, which has caused a serious impact on the development of the solar energy LED industry in China, Fig.1.

Thirdly, there is a vicious competition among Chinese solar energy enterprises. The solar energy LED industry needs a lot of capital investment, and many speculators in the past few years fancied their high profit margins, poured into the industry, resulting in a large number of poor management and operation; there are many small and medium-sized enterprises with less risk resisting capability; in the face of excessive production and changes in the fundamentals of the international market situation, many solar companies start to compete viciously, and compete at a loss, which not only has seriously impacted the normal development of the industry, but also has provided the so-called anti-dumping in foreign countries with evidence, forming a vicious circle. Most downstream LED companies are more likely to import products from large solar energy companies to ensure the product quality. Many small and medium-sized enterprises have to rely on subcontracting and other ways to survive, which will inevitably be eliminated as the large enterprises continue to grow and develop.

Finally, the withdrawal of venture capital deepens the industrial crisis, and the financing difficulties accelerate the bankruptcy of enterprises. The influx of speculative capital in the early stage led to the dilemma of the development of China's solar energy LED industry; the speculative capital is put into the solar LED industry to get high return, and the appearance of the dilemma is bound to trigger the mass evacuation, leading to a major reversal of corporate financing environment. Financing difficulties have become one of the most important factors for the reason why solar energy LED enterprises cannot continue to survive, especially for those small and medium sized solar LED enterprises that are to collapse due to incapability of selling their products, venture capital withdrawal and new financing difficulties. Some solar LED enterprises are even with mountains of debt and unable to repay the loan in time and many bankrupt-restructured solar LED enterprises have appeared. From a point of view of risk, major banks tightened the credit support for solar LED enterprises further.

## 3. ANALYSES AND DISCUSSION OF RESULTS

### 3.1. Analysis of influencing factors of credit risks of solar LED enterprises

**Risk of foreign policy**: Chinese solar energy products are mainly exported to Europe and the United States, and today with the rising of the trade protectionism, it is of great international trade risk, so the development prospect is uncertain. For example, after the global financial crisis, constrained by financial resources, many European countries re-

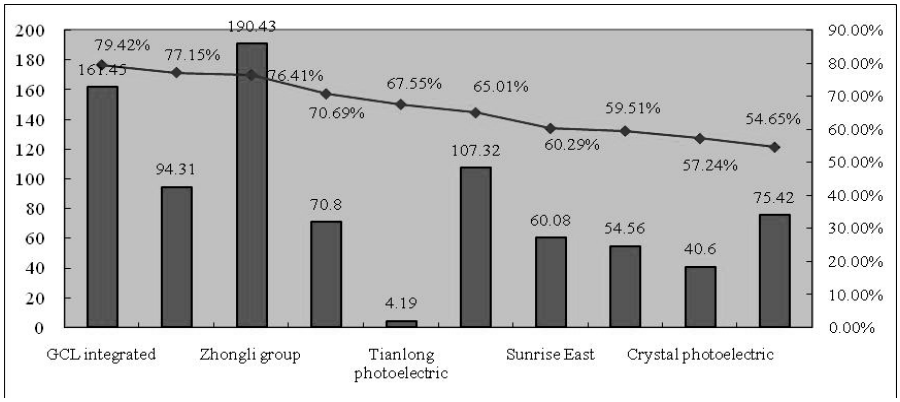


Fig.2. Liabilities of listed companies in the solar LED industry

duced subsidies for photovoltaic products, causing many of our solar energy products to lose a lot of international markets. The United States has launched a so-called 301 survey on our country for several times, and the arrival of President Trump cast a shadow over the future export of the solar energy industry. In accordance with the relevant agreements for joining the world trade organization, China should get the status of market economy country in December 2016, however, the western developed countries, led by the United States, Japan and other countries, still do not recognize our country as a market economy, which provides an excuse and basis for the implementation of trade protectionism in these countries. As an important part of the solar energy industry, the living environment of solar energy LED enterprises in China is still not optimistic.

**Exchange risk:** The products of most solar energy enterprises in our country rely mainly on exports, and the basic raw materials are mainly imported from abroad. Therefore, the production costs and sales prices are denominated in US dollars, Euros, pounds and other international currencies, while in recent years, China has gradually liberalized exchange rate control, allowing the RMB exchange rate to float in limitation, and such fluctuations must have a major impact on the costs, prices and profits of an enterprise. On the other hand, after signing the contract for purchase of raw materials and sales contract with foreign countries, it will take some time before the actual amount of money is received and paid, during which any change in the exchange rate will cause the exchange risk to the enterprise. When the RMB exchange rate goes up, the products sold actually get less return, and when the RMB depreciates, the contract for the purchase of raw materials requires more capital, both of which will cause significant losses to solar LED enterprises. For example, the devaluation of the euro and the relative appreciation of the RMB have caused great exchange losses to China's solar LED enterprises, Fig.2.

**Irrational capital structure**: any irrational capital structure of enterprises will lay financial risks, and the problems of the capital structure of solar LED enterprises in China can be divided into two kinds: First, the debt ratio is too high. The borrowing around in the blind expansion of enterprises leads to higher debt ratio, which forces enterprises to repay huge interest and makes various speculative funds reduce the further capital investment because of the pursuit of higher profit margins; banks and other institutions are also worried about risks because of higher debt ratios, making it difficult for companies to refinance. Second, the debt structure is irrational. An irrational corporate debt structure may involve a large amount of debt that needs to be repaid at some specific time, and once there are some changes in the external environment, enterprises will get into debt crisis. For example, according to the annual finical report of listed companies in 2016, the debt ratio of some listed solar energy enterprises reached over 70 %, and the debt of GCL reached 16 billion 145 million RMB, with the debt ratio being 79.42 %, ranking at the top of all, as is shown in Figure 2. The lower the debt ratio is, the worse the ability of the enterprise to further use the external funds will be, and it is bound to face greater risks of production and operation.

**Business decision-making error:** At the beginning of entering the industry, many solar LED enterprises blindly formulated management decisions of expanding investment only seeing the market demand and industrial profits, without taking into account the risks of the decline of the earnings expec-

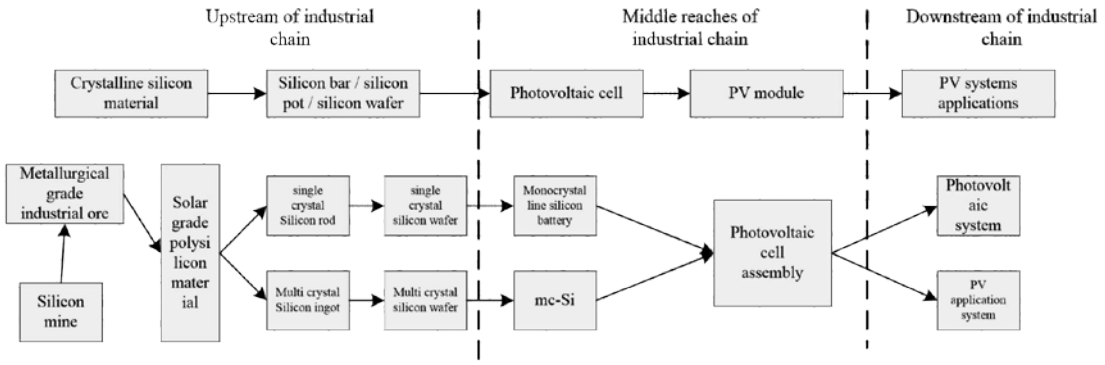


Fig.3. Basic structure chart of the industry chain of solar energy LED enterprises in China

tation and insolvency caused by the changes in the subsequent market demand. This kind of misjudgment of business decision is concentrated in the following two aspects: First, the misjudgment of the future market demand of solar energy LED industry directly leads to the difficulty in digesting for new investment projects after going into operation, idle capacity, decline in return on investment, loss, being unable to repay the loan for the new investment, and the crisis of survival. The second one is the negative effect of operating leverage. With the characteristic of greater investment in fixed assets, the solar energy LED industry needs greater investment in the early stage. Therefore, once the investment decisions made before go wrong, it will bring greater losses. As a whole, the solar energy LED enterprises in our country starts relatively late, and many management concepts come from abroad, so it also lags behind other countries, especially developed countries. As a typical energy industry, many leaders of solar energy LED enterprises in China pay more attention to cost management, but they don't pay enough attention to the management of the blood system. In particular, some large enterprises have relatively loose financing environment, and more beautiful financial statements, which further obscure the shortcomings of inadequate operational management capabilities.

### 3.2. Discussion of the proposal for the prevention of credit risks of solar LED enterprises

First of all, it is to promote the coordinated development of China's solar energy industry chain. The solar energy industry chain can be roughly divided into three parts, the upper, middle and lower reaches, as it shown in Fig. 3. The upper reach industries are mainly in the development and production of source material, such as silicon mining and single crystal, poly-crystalline silicon chip and so on, while the middle reach is mainly production battery components, and the lower reach of the chain is the application system link of the solar energy industry.

Relatively speaking, the upstream of the industry chain has more technical requirements, and the main core technology is grasped from the United States, Japan, Germany and other developed countries. But the solar energy LED enterprise in our country lacks the core technology generally, and using relatively backward production technology not only results in the increase of production cost, but also leads to the shortage of product quality, making the solar energy LED industry in China rarely enter the upper reach, and mainly concentrate in the middle and lower reaches of the industrial chain. It shows the unfavourable situation of subordination and low profit margins. Therefore, the development of solar energy LED industry in China must promote the coordinated development of the industrial chain of solar LED enterprises, and scientifically build and occupy the industrial chain and favourable position, in order to ensure the healthy and sustainable development of the industry as a whole. At present, developed countries have realized the global allocation of industrial chain. They use their own technical advantages, and produce high purity poly-silicon in their country to obtain high profits; however they transfer the middle and lower reaches industries with high energy consumption and heavy pollution to developing countries, and make full use of the cheap labour force to reduce production costs. Therefore, in the course of adjustment, in addition to the use of labour dividends and resource bonuses, the solar energy LED industry chain in Chi-

na should also occupy the more critical and high value-added links in the industry chain, break technical restrictions and change the traditional extensive and labour-intensive model of development.

Secondly, attention should be paid to the current assets and cash flow of solar LED enterprises. In terms of industry, the solar LED enterprises belong to the manufacturing industry focusing on assets and resources. Although they are bound to have a certain asset size, especially for those listed large enterprises, the company's own debt to equity ratio is still very important and is more critical than total assets in the financial statements in some cases. The ratio of equity to debt can clearly reflect the ratio between the invested capital and the debt of an enterprise, and in the face of bankruptcy and liquidation of enterprises, the higher this ratio is, the better the ability to repay the debt will be, and in turns, it has higher credit risk. That is to say, the enterprise's equity debt ratio is directly proportional to the credit risk of the enterprise.

In the presence of credit risk of enterprises, enterprises usually can only call liquid assets to repay their debts, and the profits in the financial statements, as well as the fixed assets cannot be used in time for the repayment of the debt; while corporate creditors generally enjoy only fixed interest income, and the profitability of an enterprise does not have any direct benefit to the creditor. To this end, from the point of view of creditors, whether an enterprise has enough current assets and healthy cash flow is the key to risk prevention, and it is not to focus on the analysis of the future profitability as you choose stocks. Of course, the future expectation development and profitability of enterprises are equally important, directly affecting the future quality of liquidity asset and cash flow of enterprises. Modern enterprises can manipulate or modify the book profits of enterprises through many ways, such as asset impairment, and even some company use investment and financing and other means to optimize debt in the short term. But it's harder for companies to modify cash flows. Therefore, the investment focusing on the risk prevention and management of corporations pays more attention to the financial analysis of cash flow, studies the existing problems in the cash flow of the enterprise, the reasons for the problems and the future trends, with these being the important investment decisions.

Thirdly, pay attention to the abnormal changes of other important accounting data, and strengthen the supervision of credit market. The credit risk prevention of the solar energy LED enterprise needs to pay more attention to the accounting index of enterprises such as provision for account receivable, falling price reserves of inventory withdrawing and impairment provision for long and short -term assets. For example, in a relatively unfavourable period of the development of the whole solar LED industry, some enterprise has made a very beautiful financial data, and this kind of data can be with a large amount of false content, which can be made by inflating the accounts receivable. For example, before the debt default, Shanghai CHAORI Company had ever presented more favourable corporate financial conditions, and showed stronger profitability and earnings expectations than most enterprises in the same industry at the same time, but this beautiful book data could not stop the company from running out of business and defaulting on its debts.

Under the condition of the market economy, the occurrence of credit risk incident of enterprises is often unavoidable especially when China has not yet established a mature capital market and there is still a big gap between China and developed countries in risk prevention and management. At this point, the normal corporate debt default can also play an important role in raising awareness of the risk of all walks of life, and can also play a part in promoting the continuous reform of China's capital market. However, if the credit risk incident of enterprises cannot arouse enough attention in China's capital market, and take it as an opportunity to improve risk prevention and management in a timely manner, there will inevitably be more serious adverse consequences in the future, which is not conducive to the healthy and sustainable development of China's capital market and even the whole economy. With the deepening of China's economic openness, interest rates are gradually moving towards marketization, and the possible credit risk of corporate debt has gradually improved, however, from the perspective of China's regulatory level, we should not give up eating for fear of choking, and we should fully recognize that this is the necessary stage for the development of our national debt market. We should promote the healthy development of China's bond market from the perspective of increasing supervision and increasing punishment, and especially those enterprises who deliberately take false information to deceive investors should be severely pun-

ished. It should build a more scientific and marketing reasonable system of supervision, constraint and default punishment step by step, make full use of the supervision and restraint of the third party of underwriters and credit rating agencies in the course of bond issuance on the premise of drawing full attention to the advanced and mature experience of developed foreign countries and considering the current situation in China's economic development, to create a more fair and transparent bond market environment for our country and reduce unnecessary credit risk problems of enterprises as much as possible.

Finally, fully stimulate the domestic demand, and achieve the cross-border integration and development of the solar energy LED industry. The solar energy industry has become an important part in China's steady development, and we must change the development model as soon as possible, fundamentally changing the past export-oriented development orientation and strategy and paying more attention to the development of the domestic market. Our country has already started the golden sun program, and the state has guided and promoted the construction of solar power stations from policies and financial support, which has greatly increased domestic demand for the solar energy industry. Many domestic solar companies have seized this great opportunity for development, and devoted themselves to the development of the domestic solar LED industry, which is bound to further accelerate the domestic demand of the solar LED industry in China, gradually improve the profitability and the ability for independent research and development of solar LED enterprises in China, and promote the sustained and healthy development of the whole industry. In addition, the state should establish and improve a variety of supporting mechanisms; for example, the pricing mechanism of Internet surfing should be established as soon as possible to attract more investment in the industry. We should give full consideration to the characteristics of the solar energy LED industry, and leave enough profit space for the solar energy LED enterprises from the mechanism setting. We should also consider the differences in different regions and implement the policies according to the local situation.

Under the background that China's economic development has entered a new normal state, the entity economy including manufacturing is faced with large impact, so the solar LED industry should use the modern information technology to achieve better industrial integration and cross-border integration and development, closely combined with the characteristics of the era of Internet plus. We should vigorously develop new power networks and connect and integrate the distributed energy nodes and the power network effectively, based on the information technology and intelligent technology. We should use the Internet to realize the integrated microgrid, coordinate the scientific development of the whole industry chain, and enhance the core competitiveness of the industry.

## 4. CONCLUSION

The research results show that after experiencing rapid expansion and development for several years, Chinese solar energy enterprises, especially the LED enterprises have been stuck into the management dilemmas such as overcapacity, financing difficulties and weak sales growth, and many companies have the potential to become the next bonds default of Shanghai Chaori. Therefore, China's bond supervision departments should attach great importance to the prevention and management of enterprise risk, avoid similar incidents and reduce the negative effects for investors and the bond market as much as possible. China's regulatory authorities should focus on the issuer's own risk prevention and management, increase supervision and management and the intensity of punishment for breaking contracts, and gradually establish the information disclosure system of bond issuing enterprises suitable for China's national conditions. At the same time, we must educate and guide the investors to keep a clear mind at all times to recognize the possible high credit risk in the bond market, and gradually guide investors to invest more steadily. In addition, we should also guide the orderly competition of China's solar energy LED enterprises through policies, enhance the comprehensive competitiveness of solar LED enterprises, and reduce the risk of enterprises' performance.

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# RISK ANALYSIS OF INTERNATIONAL TRADE FINANCING OF CHINESE LED ENTERPRISES IN CHINA

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## ABSTRACT

With the immediate looming problems in environment and energy the world is facing today, renewable energy industry, such as the photovoltaic power generation, is under rapid development. Photovoltaic power generation, though currently in the early stages of development, is of great potential for development with its stable and high growth rate. Among them, the LED field is also an important direction of photovoltaic applications. This paper first briefly introduces the constituent elements and structure of trade innovation system of PV industry. Then, it analyzes the status quo of international trade financing of PV enterprises provided by commercial banks and the risks they are facing on the basis of an empirical research. The results show that China's photovoltaic enterprises are facing challenges brought by the increasingly fierce international trade competition. Therefore, small and medium PV enterprises, no matter for their internal or external development, should change their international trade financing state, for which, vigorously improving the financing environment for small and medium enterprises is undoubtedly the most realistic and wise choice.

**Keywords*:*** photovoltaic enterprise, International trade, commercial bank, financing risk

## 1. INTRODUCTION

Taking the international trade finance of PV enterprises in China as its research object, this paper analyzes the problems existed in the financing process of PV enterprises from the perspective of both enterprises and banks. The rapid development of photovoltaic enterprises highlights their ever-increasing demand for trade finance and the fast development of the international settlement business in banks provides great convenience for photovoltaic enterprises to expand their international trade financing. The reasonable expansion of trade finance of photovoltaic enterprises is of great practical significance to promote their steady development. In addition, LED light source, as a green light source, has the characteristics of high luminous efficacy, low power consumption, long service life, high safety and reliability. Japan is expected to replace incandescent and fluorescent lamps with lamps luminous efficacy two times higher than fluorescent lamps. It can save up to 6 billion litres of crude oil a year. With the economic development of our country, the lighting electricity consumption in our country will be greatly improved, and the research and application of green energy-saving lighting will be paid more and more attention. On this basis, the LED light source can be associated with the photovoltaic solar energy, hoping to make the night lighting seamlessly connected with the solar energy reserves during the day. This will be a big step towards green environmental protection. Thus, it is more necessary to make a deep study on the risk of international trade finance of PV enterprises in China. Since the innovation of trade system is the important basis for the expansion of trade finance, therefore, the elements and structure of photovoltaic

industry trade system are fully examined firstly and then the current situation of commercial bank's international trade financing for photovoltaic enterprises and the achievements they have obtained so far. In its final part, this paper elaborates the strategies of Chinese PV enterprises to cope with the international trade financing risk in detail. With the sound development of international settlement, the trade finance business of photovoltaic enterprises will certainly be expanded since it is helpful to meet the challenges in the open market, to develop the local economy, and promote the sound and rapid development of society and economy. At the same time, it is also conducive to the healthy operation of the local financial sector, and therefore will reduce the cost of financial supervision department in playing the supervisory role. Therefore, the city commercial banks should develop international settlement and vigorously expand the international trade finance for photovoltaic enterprises so that they can improve their business flow in their effort to innovate their business.

## 2. THE RESEARCH REVIEW

Along with the rapid development of photovoltaic industry since the beginning of this century, the innovation of this industry has attracted the attention of many researchers. By far, some research results have been gained in this field, mainly from foreign scholars with empirical research as the most widely used method and innovation system theory as the basis of their theoretical framework. [1]. However, few research has been carried out by domestic scholars, and there is no clear theoretical framework and research methods. The research on the development of photovoltaic industry in foreign countries often take the developed countries, such as Japan, Germany, Britain, Spain and other photovoltaic industry leading countries as the objects for their empirical researches [2]. Watanabe made an empirical study on how Japan successfully achieved a "virtuous cycle" in the photovoltaic industry. The results show that Japan's Ministry of International Trade and Industry initiated development of photovoltaic industry under its " Sunshine Program", a research and development (R&D) program on new energy and has finally created a virtuous cycle between R&D, market growth and price reduction [3]. In particular, the Sunshine Program aimed to encourage broad cross-sector industry participation; to stimulate cross-sector technology development so that it could have great spill over effect; and finally, to induce substantial industry investment in PV R&D, leading to a rapid increase in the industry's knowledge stock on PV technology. The increase in this technology knowledge stock contributed to the significant decrease in the cost of solar cell production, which induced a further increase in demand for solar cells (and hence production) [4]. In turn, this increase in demand/ production induced further PV R&D, thus creating a "virtuous cycle" between R&D, market growth and price reduction [5]. A. Nagamatsu studied the diffusion trajectory of innovation of the PV industry in Japan, and believed that the success of Japan in leading the development of photovoltaic industry in the world could be attributed to two interrelated and complementary factors: technology and government intervention [6]. In terms of technology, photovoltaic technology, just like semiconductor technology, was a technology that involved a web of related technologies and therefore could benefit both from the learning effect and economies of scale. The interdisciplinary nature of PV development could also trigger the spill over effect of technology, which, by linking to the learning effect, could bring the technology to its greatest effect. The Japanese Ministry of Health, Labour and Welfare initiated the development of photovoltaic industry with the above-mentioned factors: encourage broad cross-sector industry participation, and encourage learning and the inter-firm technology spill over effect.

## 3. ANALYTICAL FRAMEWORK

### 3.1. The elements and structure of photovoltaic industry trade innovation system

According to the theory of innovation system, government, enterprises, universities and research institutions should cooperate with each other. Venture capitals are closely involved in the process of technological innovation, including the division, cooperation and interaction of labour, the performance of technology, and the creation of innovation system [7]. The participants of China's photovoltaic industry innovation system include: photovoltaic enterprises, research institutions and universities, government, intermediary organizations and venture capitalists. In its research re-

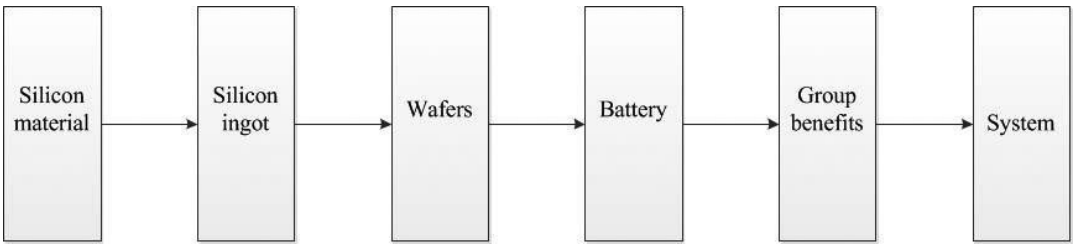


Fig.1. Structure of PV industry supply chain

port, the photovoltaic group introduces the value chain of photovoltaic industry [8].This value chain actually tracks all the distinct segments of the manufacturing processes of the current global PV industry, including silicon, ingot, silicon chip, and system. The International Energy Agency (IEA) report describes the supply chain structure of the PV industry, as shown in Fig. 1, which also covers photovoltaic devices, module sand, thin film cells besides the above mentioned segments.

As the photovoltaic technology is naturally evolved from the semiconductor technology and industry, China's first photovoltaic enterprise was transformed from the former semiconductor company [9]. In 1970s, three Chinese semiconductor manufacturers began to produce photovoltaic cells by modifying their former solar cell production line. Later, the introduction of seven photovoltaic cell production lines from the United States, Canada etc. marked that China preliminarily owned the capacity to manufacture solar cells. By 1995, China already had six solar cell manufacturers [10]. And after 40 years of rapid development, the number of photovoltaic enterprises in China has reached more than a thousand. By 2009, Chinese photovoltaic enterprises had formed its industry chain to manufacture crystalline silicon, which could be divided into five categories: solar-grade polycrystalline silicon manufacturing; solar cell processing; silicon solar cell manufacturing, solar module packaging and system integration. Fig. 2 shows China's photovoltaic products.

### 3.2. The current situation of commercial banks' international trade financing for photovoltaic enterprises

The commercial banks find it difficult to finance photovoltaic enterprises in their international business because most of the photovoltaic enterprises can't meet the financing standards of the bank in terms of their financial indicators or the characteristics of their projects. Traditionally, commercial banks will give consideration to some essential components such as the scale of the enterprise, is net assets, debt ratio, profiting ability and guaranty in making their loan decisions. In addition, many photovoltaic companies fail to get finance from bank because their credit standing can't meet the requirements of the bank. Since banks care each specific business transaction, in the process of trade financing, they will carefully examine the actual background of each enterprise that is applying for a loan and its historical reputation. To increase the safety of their loan, the bank will designate a special account for the loan-applier to put their capital in their trading process to ensure the risk of each loan can be controlled. For some PV

Fig.2. PV products in China

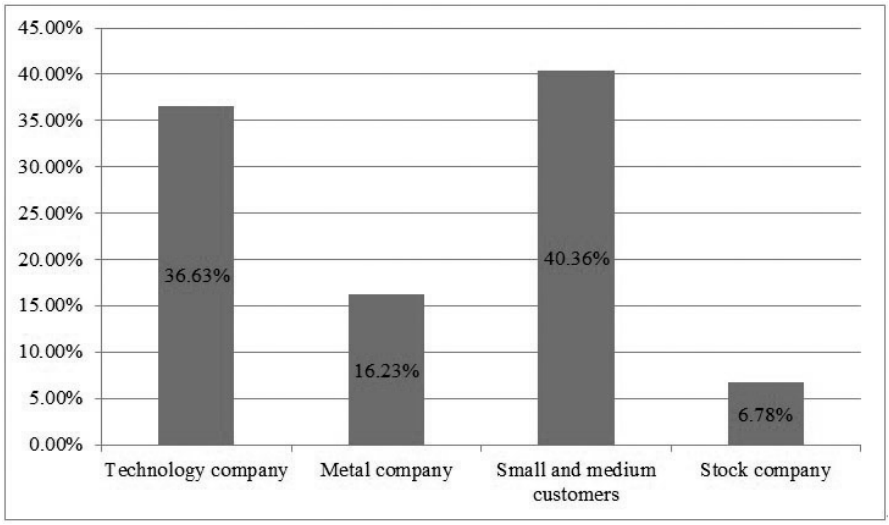


Fig.3. Proportion of the financing of the international business department of commercial banks

companies that can't get finance from the bank since their financing indicator fails to meet the requirements of the bank, trade finance can offer them the opportunity to gain loans from the bank by their continuous and cycled real-time transactions, and naturally alleviate their financing pressured to some extent.

Since the trade finance approval process is relatively simple, companies can get the necessary funds at a faster speed. Due to the limitations of their funds, the photovoltaic enterprises are always confronted with a tense capital chain, and therefore need to get finance more timely. The traditional liquidity loan is too cumbersome since banks need to conduct a rigorous investigation on the basic situation, financial indicators, development prospects, and financing of the loan-applying enterprise before the approval, which has already been unable to meet the financing needs of enterprises. In recent years, domestic banks have begun to pay attention to trade finance and readjusted and streamlined its process so that banks can issue loans to the PV enterprises so far they are transparent with their business background and are sure they have a sound credit standing. However, due to the long prevailing philosophy "to support the big and let off the small" in the bank, banks prefer to invest their limited capital to the big enterprises. However, banks may lose their potential customers, especially those in-growth small and medium enterprises which are not so urgently in need of finance. Fig. 3 shows the proportion of trade finance in the international business departments of the city's commercial banks.

### 3.3. Strategies of chinese pv enterprises in coping with the international trade financing risk

Theoretically, the risk of trade finance is relatively small compared with the bank's other loans since it will hurt the enterprises themselves if they default. However, photovoltaic enterprises still find it difficult to get timely trade finance due to the difference in the understanding and operation procedures of different financial institutions, the financing quality of different banks and the quality of their assessment personnel, and the different understanding of the defects of photovoltaic enterprises of financial institutions. However, trade finance is more profitable if the commercial banks can maximize the profit while minimize risks. Therefore, they need constantly innovate their products and service in the process to comprehensive develop international trade financing business for the small and medium-sized import and export enterprises, and improve and strengthen their management mechanism and management system so that they can expand their international trade financing business as well as enhance their competitiveness. Since the demand of photovoltaic enterprises for loans is usually small but urgent, and can repay their loans with turnover within a short period, city commercial banks must speed up their innovation by providing corresponding and diversified products to deal with the special characteristics of photovoltaic enterprises. The settlement business today, which has developed for a long time, is no longer simply a fund. It has been a common practice for the inter-

**Table 1. General strategies of international trade financing**

| | |
|---|---|
| Strategy 1 | Innovative products and services |
| Strategy 2 | Internal structure integration, process optimization |
| Strategy 3 | Perfect risk control means |
| Strategy 4 | Improve the credit rating of photovoltaic enterprises |
| Strategy 5 | Implement and strengthen the supervision of PV companies after the loan |

**Table 2. Statistical properties of the correlation coefficient distribution in three periods**

| Period | Average correlation coefficient | Variance |
|---|---|---|
| First period | 0.5036 | 0.0639 |
| Second period | 0.2569 | 0.0412 |
| Third period | 0.4563 | 0.0636 |

national banks to provide trade finance along with settlement. Banks need to understand the market demand, continue to introduce new products according to the customer's needs in foreign trade and payment. They also need to learn from the practice of the international banks about the traditional and new financing methods, and timely develop new and appropriate products for their customers so as to support the normal import and export business of photovoltaic enterprises and meet their trade financing needs. In addition, innovation should be carried out in a variety of aspects, such as in loan business which should not only limit to finance by credit but should gradually expand to financing on payment and invoice in export process and the open documentary and standby letters of credit and other business forms in the import process to meet the various needs of photovoltaic enterprises.

Settlement and financing are usually conducted in two separate departments of the bank, which is not conducive to the international trade financing since it is carried out on the combination of these two aspects. What's more, the separation of settlement and financing is also not good for the banks in establishing an integrated working system in which they can mutually supervise and cooperate with their working partners. Therefore, banks need to adjust their internal organization. If banks can dissolve their international business departments and set up the departments that can comprehensively manage the credit trade finance and integrate foreign currencies, it will undoubtedly benefit to the development of enterprises by providing them more efficient and convenient services. At the same time, in the actual operational process, banks need to establish a relatively large-scale credibility system and implement credit rating on photovoltaic enterprises so as to reduce the difficulties in customer management, accelerate the approval process, and increase the approval opportunities of those with sound credit to meet the needs of photovoltaic enterprise for funds. In addition, they can provide better services for photovoltaic enterprises by improving the quality of their loans. International settlement is a typical intermediate business of banks, which is of low risk and will not occupy the capital of the bank. International trade financing, on the other hand, involves asset and is of relatively higher risk. In addition to the risk in credit and market of all financing business, the international trade finance also has to face the risk in documents, transportation, fraudulence and politic. Therefore, the establishment of risk prevention system is one of the prerequisites for the development of international trade financing so that effective measures can be taken to control risk. Table 1 is the general strategy Chinese PV enterprises used in their international trade finance.

In order to study the characteristics of the PV market in China in different periods, a statistical network is set up to assess the financing risk in three different periods, namely, the financial crisis period, the rapid development period after the financial crisis and the industrial adjustment period. The

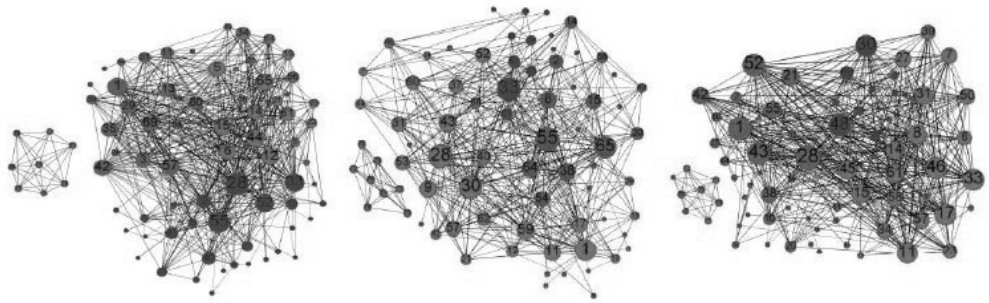

Fig.4. Risk network values in three periods

construction of financing risk network is shown in Table 2.

The average correlation coefficient is used as the value to assess network risk in many literatures. However, for each period, the distribution of risk network correlation coefficient is different and the relevant dispersion structure can be seen in the higher places. In order to better reveal the network structure, parameters are set to value the risk of network.

$$\theta = c_{ij} + 3\sigma, \quad (1)$$

where $\sigma$ is the variance of the correlation coefficient. As can be seen from Table 2, $\sigma$ is larger in the first and the third period, which indicates that the system financing risk in PV market is greater, and the fluctuation of average correlation coefficient is relatively tense.

## 4. RESULT ANALYSIS AND DISCUSSION

As can be seen from Fig. 4, there is a clear partition structure in the financing risk network of photovoltaic enterprises. In the third period, the number of partitions is 4, 5 and 4, respectively, which shows that companies need to link more closely to reduce the risk of financing when the system risk is high. In terms of its value chain of photovoltaic industry, Fig. 4 shows that in the first period, enterprises in the same partition are usually located in the same value chain. And so is in the third period. In the second period, however, the majority of the enterprises in the same partition are located in the different parts of the industrial chain and scattered in a broader divisions. The results show that the impact of high-risk events has a higher relevance correlation on the main products of the same business in the financing of PV enterprise.

## 5. CONCLUSION

Photovoltaic enterprise financing is a global problem. With its accession to the WTO, China's photovoltaic enterprises will further develop and integrate with the world, and the development of photovoltaic enterprise financing will become increasingly important. This paper introduces the theory of financing, and analyzes the current financing situation of PV enterprises in China and the reasons leading to their financing difficulties. Then, it studies the problems that commercial banks are facing in their financing to Chinese PV enterprises based on the latest research literature and achievements home and abroad, so that they can expand their financing business in the fierce competition among banks and increase their finance to PV enterprises. The data collected from different channels and in different ways of the PV enterprise financing in the research process are given to support the author's perspective. However, this paper also has its limitations due to the limited capacity of the researcher. For example, the trade value used in this paper is about all the photovoltaic products and is not classified though a comparative study of the trade structure of various photovoltaic products can better reflect the competition pattern of international PV trade. This paper only mentions several listed photovoltaic enterprises which although are representative but not comprehensive. The follow-up researches need to consider more photovoltaic enterprises to make it more convincing.

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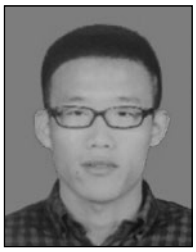

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# THE APPLICATION OF LED LIGHT SOURCE IN MODERN LANDSCAPE LIGHTING DESIGN

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**ABSTRACT**

With the development of society and the progress of lighting technology, the use of LED light source for modern landscape lighting design has become a hot topic in modern society. In this paper, the physical properties of LED light source, the characteristics of LED light source in the modern landscape lighting design, as well as the principles, methods and design steps in the design process were studied. At the same time, the LED light source was controlled by computer program. And the rendering method of LED light source array in landscape lighting was also analyzed. Finally, the results were verified by a specific example. It is proved that the new design scheme can realize the coordination of lighting facilities and landscape, and finally make the environment more beautiful.

***Keywords:*** LED light source, landscape lighting, environmental facilities

## 1. INTRODUCTION

Green energy saving is the necessary requirement for the sustainable development of human society, which not only meets the needs of modern people's comfort, health and longevity, but also does not harm the greater demand for energy and resources for future generations. In the field of lighting, from firewood to oil lamps, from candles to incandescent bulbs, a variety of lighting equipment has been accompanied by human beings today. With the development of science and technology, the lights sources are developing continuously [1]. At present, the light source with higher power saving efficiency and longer service life is the best solution for lighting requirements. With its high colour rendering index, small size, light weight, simple accessories and structure, high safety factor, energy saving, long life and so on, LED light source will impact the traditional light sources market [2]. With the further development of the LED light source with high-power, high brightness, high efficiency and low cost direction, designers should also consider and design it from the perspective of ecological environment protection and sustainable development. In addition, designers should also adopt the green way of thinking and intelligent methods, so as to make it occupy an increasingly important position in the environmental facilities lighting industry [3]. The design and processing of the LED light source in the modern landscape lighting can best reflect the city's civilization and cultural quality, which is also an important link to reflect the taste of the city and improve the interest of life. It is not only a direct contact object for people to experience the urban environment, but also an important carrier of urban style. At the same time, it also involves the study of art, the study of environmental psychology and human behaviour patterns, the urban life and the realization of good economic benefits [4]. LED lighting design is one of the important ways for modern landscape lighting design to move towards sustainable development. This concept has been very common in the world, and now many designers have gradually realized its great ecological significance, as well as social and economic benefits. The utilization of LED in landscape lighting design has

become a mainstream in the design field. And there are many successful works, which is one of the effective ways of sustainable development of landscape lighting [5].

## 2. STATE OF THE ART

### 2.1. Development of LED lighting technology

Around 1960, the world's first GaP light emitting diode was made. The world's first commercial light emitting diode (LED) was made of germanium in 1965. Shortly thereafter, Monsanto and Hewlett-Packard Co also introduced commercial LED made by GaAsP material. After 1970, LED began to enter the market. At that time, LED was mainly in red, and because of the low luminous efficacy, the flux was very small [6]. The early red LED can provide about 0.1 lumens of luminous flux per watt, which was 100 times lower than the ordinary incandescent lamp of 15 lumens. Therefore, it can only be used as an indicator in the electrical equipment and instruments.

With the development of the core material, the structure, the packaging technology and the driving circuit technology, the type of LED light is increasing, and the luminous efficacy and light energy are also increasing. At present, LED has been widely used in the field of scientific research and production, promoting the development of industrial construction and the growth of the number of market applications. In the early days, due to the limitations of LED colour, luminous efficacy, luminous flux, optical power and price, LED is mainly used in indicate areas, such as electronic and electrical, thermal instrumentation, automation system, communication setting, space development, household appliances, transportation as indicator lights, warning lights, signs and information signs advertising, etc. [7].

With the continuous enrichment of LED colour, especially the successful development of high efficient, high brightness white LED in recent years, and with the continuous development of white LED technology, luminous efficacy is raising, and prices are gradually reduced, making the application of LED in the field of lighting possible. LED will be favoured as a new generation of energy-saving green lighting [8]. This kind of LED light source is a kind of the new white LED light source based on blue LED, which is widely used in such fields as emergency lighting, decorative lighting, home lighting and so on. LED is applied in the field of lighting, which involves the development of material devices, optical structure design, packaging materials, electronic circuits, lighting development, lighting effects and visual matching, and other interdisciplinary fields. It is generally believed that LED will replace the traditional incandescent lamp, fluorescent lamp and high intensity discharge lamp in the near future, and become a new type of light source and bring a revolution in the field of lighting.

### 2.2. Application status of LED lighting technology

In view of the modern landscape lighting market, LED has the characteristics of electricity saving, rich variety, bright colour, long life and so on. It has been widely used in landscape lighting engineering. In 2008, the domestic landscape and decorative lighting market size was 13 billion yuan, in which only the application of LED landscape lighting in Beijing Olympic Games was nearly 500 million yuan. With the construction of Shanghai World Expo in 2010 and the acceleration of urbanization process, the proportion of LED applications in the field of landscape lighting will further increase, mainly used in the decoration of important buildings, streets, commercial centres, places of interest, gardens, lawns, leisure and entertainment places, as well as the commercial lighting integrated with decoration and advertisement. Under the impetus of the government, the LED lighting with low power consumption has strong market competitiveness in the landscape lighting market. Therefore, LED lighting has been increasingly applied to the landscape lighting market [9].

New energy will gradually replace traditional energy as the driving force to promote social and economic progress. The new energy is often accompanied by the birth and progress of new technology. LED industry is a typical incubator for new energy. Industry experts believe that the advantages and risks of China's LED industry coexist, and it is necessary for the government to increase support for industrial development in terms of policy and funding.

The rise of the LED lighting market has also brought many opportunities and challenges to the manufacturers. LED has become the new darling of outdoor lighting. Solar outdoor lighting, new

**Table.1 Comparison between LED and current lighting equipment**

| Lighting mode | Characteristic |
|---|---|
| LED | With low calorific value, low power consumption, long life, fast response, small size package, it is easy to develop into a short thin products |
| Fluorescent lamp | Fluorescent lamp is power saving, but the waste is mercury pollution and fragile |
| Incandescent tungsten lamp | Low efficiency, high power consumption, short life, fragile |

lighting, and intelligent control system have gradually become the mainstream trend [10]. Due to the impact of national policies and other factors, the current outdoor lighting is in the direction of energy conservation. LED has replaced neon and has become the main outdoor lighting fixture. LED has been widely used in landscape lights, garden lights, underwater lights, buried lights, lawn lights, etc. Outdoor lighting, especially landscape lighting products, should be toward the direction of not only energy saving but also intelligent development. In the procurement of outdoor lights, in addition to the need for decorative lighting, more and more businesses require lamps to meet the needs of various lighting effects. As a result, various types of landscape and decorative lights controlled by computer intelligence have become the popular trend of outdoor lighting.

## 3. METHODOLOGY

### 3.1. LED light source

LED is the abbreviation of Light Emitting Diode. The schematic diagram of structure is shown in Fig. 1, using the principle of semiconductor *p-n* – junction luminescence.

LED is a point light source, different from the current energy-saving lamps or incandescent lamps on the market. Point light source, as the name implies, is a point of light. However, when the light is emitted at this point, another important feature is that only one direction is bright [11]. LED light source has the advantages of low voltage power supply, low energy consumption, strong applicability, high stability, short response time, no pollution to the environment. Although its price is higher than that of the existing lighting equipment, it is still considered that it will inevitably replace the existing lighting devices. Table 1 is a comparison between LED and current lighting equipment.

### 3.2. The use of computer programs to control the change of LED light source for modern landscape lighting

There are different kinds of lighting software for different purposes in the field of LED lighting. Their use has reduced the heavy manual labour, and has completed lots of previously impossible work, which will promote the development of lighting industry. In the field of lighting design, there are a lot of content related to the mechanical, optical, lighting applications, etc. The most commonly used software is ASAP.

ASAP is a commercial software. It has a powerful mechanical simulation function, and can simulate almost the entire three-dimensional geometric models with good interactivity. Thus, before making prototype system or mass production, the user can do the simulation of optical system. It applies the optimized Monte Carlo method to non-sequential ray tracing. In other words, the light can go through the surface in a non-sequential manner. Compared with the traditional ray tracing method, it is faster and more accurate, which can cal-

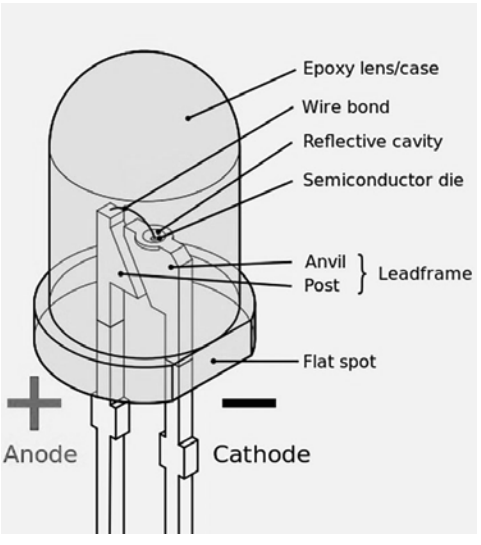


Fig.1. LED structure scheme

culate and analyze millions of light rays in a short time. At the same time, it can be used together with other software, through a specific conversion function to share graphics or data files [12]. Users can not only define some simple geometry and light source, but also can define a complex optical system by writing instruction code.

### 3.3. Use of LED light source conversion to achieve the modern landscape lighting at night

The use of new energy refers to the conversion of solar energy, wind energy into the electricity needed to achieve the city square night lighting. In this way, the excess energy can be transferred to a place where there is lacking of electricity, so as to better save energy [13]. As shown in Fig. 2, according to foreign media reports, a new type of intelligent LED street lighting system has come out. This kind of street lamp can use solar energy and wind energy according to the change of weather. This street lamp is called Light Blossom. The lamp holder adopts the shape of the flower, and the whole flower can automatically control the opening and closing when the energy is obtained. The lamp post is equipped with an automatic induction device, and when someone closes, it can automatically open the LED lamp on the lamp post to facilitate close lighting.

### 3.4. The dominant position of LED lighting design in modern landscape lighting

The first was the shape design. The design of the modern landscape of the city reflected the whole city. Therefore, the form of the lamp must be able to reflect the positioning of the city. Design concept must reflect the spirit of innovation, to make the design novel and attractive. At the same time, advanced technology should be adopted to coordinate the design of unified pavement environment and lighting design and create the optimization effect of scene of day and night [14]. In the city square, the shape of the LED lamp can be designed according to the function and theme of the square.

Fig.2. New street lamp Light Blossom

The second was the design of the structure. Fig. 3 is showing LED module assembly structures, from left to right, which were backlit schematics of the side entry, the straight down, and full LED.

LED display technology was mainly related to a three lamp arrangement method of three basic LED colours. There were characteristics of the arrangement: the distribution of each LED was uniform. The whole display screen was composed of RGB triangles. In its constituent elements, the orientation order was: R was at the top left, G was at the top right, and B was below. At the same time, on the display screen, they constituted the RGB triangle. Moreover, taking this as the basic unit, they were evenly distributed on the display screen, and were regularly spread out. The arrangement solved the product cost difference caused by the LED material quality of the existing display screen, and simultaneously solves the problem of heat dissipation. Under the premise of improving the display effect, the cost of materials was greatly reduced.

Finally was the application of materials. In the design, the material of the lamp body was generally made of anodized aluminium alloy. In the design of the lamp body, there was no opening on the upper part of the whole lamp body. The whole process was aluminium alloy die-casting moulding. And there was no seepage and dust-proof troubles about the upper part of the whole. Therefore, only the light room with the light body in the downward direction and the electrical compartment needed protection. In this way, the protection problem was simple.

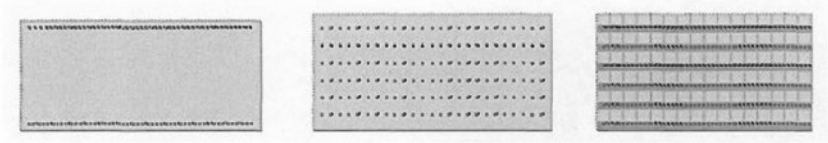

Fig.3. Schematic diagram of LED display

**Table.2 Comparison of lighting methods of environmental facilities in city square**

| Illuminated object | Lamp selection | Projection direction | Artistic effect |
|---|---|---|---|
| Sculpture lighting | Narrow beam lamps should be selected with the appropriate light source, to avoid the direction of the visitors and to avoid glare | Side projection was adopted. Not from the positive side of the uniform irradiation, a strong three-dimensional lighting effect can be created | Lighting should be from the characteristics of sculpture, especially for the key parts such as: head, expression, material, colour and the surrounding environment |
| Waterscape lighting | The choice of lamps should be based on the height of the waterscape. The floodlight lamps needed to have a wide or narrow distribution of light, the light needed to choose a wide or narrow beam lamps | The surface of the water was illuminated by the way of the top and bottom light, mainly using the water landscape and the shore of the trees and the railings of the lighting in the water to form a reflection | Reflection and the real scene were created to create a contrast, foil, positive and negative contrast and reflection |
| Road lighting | In general, the fingerprints can be set on the ground to make the projection lamp light effect, and on the basis of road lamp width, wide or narrow beam can be selected | Through the use of light and the fence around the trees, the lamp was hidden or did the ground floodlight treatment | Road was the context of the square. From the entrance, visitors were led to various attractions. The path twisted and turned, creating a different walking scene |
| Seat lighting | Lighting lamps should be used to shine the light way, and do floodlight on chairs below the outer contour | Projection angle should be from top to bottom, so as to avoid glare | Seats should be clearly distinguished by the visitors, so the lights and other surrounding objects must be distinguished |
| Plant lighting | Green lighting should avoid the use of green light at the intersection of traffic. Narrow beam lamps should be selected to match the appropriate light source and to avoid the direction of visitors | Up and down lights are two basic lighting methods of green lighting | According to the type and location of the plant, the artistic effect of the subject was made |

Only using silicone rubber strip for waterproof and dustproof can achieve the protection level. Outdoor lamps needed to be expose to the environment for a long time. The surface treatment must be corrosion resistant, and the polyvinyl acetate electrostatic spraying was a good choice. It conformed to the principle of green design, saving energy, environmental protection, and pollution-free, high production efficiency and so on. It can also achieve a wide range of colours, making the landscape colour planning have a variety of possibilities. In the connection part of the lamp, the stainless steel fasteners were selected.

### 3.5. Rendering method of LED light source array in modern landscape lighting

LED light source array referred to the use of point, line, surface, and the overall layout to achieve a combination of lighting and rendering objects to obtain a certain artistic effect. Aiming at the illumination calculation and distribution of LED array in LED based lighting, the simulation of LED array in the design and distribution and more detailed analysis certainly played an important role for the design of a more perfect LED based lamps [15].

Because LEDs are a kind of incoherent light sources, the light intensity of two LED on a plane was a single overlay (multiple LED). The array distribution of LED array was mainly studied. According to the different array distribution, it was divided into surface arrangement and stereo arrangement. Surface arrangement can be divided into plane arrangement and surface arrangement. In the plane arrangement of light, with no angle between axes, multiple LED was arranged in uniform, and was arranged on a plane substrate to form a light source with a certain area.

### 3.6. Comparison of lighting methods of LED light source in modern landscape

Lighting must be set to meet the functional lighting as a precondition. According to the inherent characteristics of landscape, the function of landscape can be fully played out. First of all, the landscape lighting of the surrounding buildings should be integrated with the lighting of the landscape, so as to coordinate the lighting around the road and the inherent culture together, as shown in Table 2.

## 4. RESULT ANALYSIS AND DISCUSSION

Through the research above and the comparison of LED light sources in modern landscape, a central square of a city was selected as an example, and a simulation of landscape lighting design was carried out. The simulation results were shown in Figs. 4, 5, 6.

Through the above simulation images, it can be found that the use of LED light source for modern landscape lighting design can fully reflect the design of the regional, place and its uniqueness. At the same time, it can avoid the light pollution and glare to the greatest extent, fully meeting the current requirements for green design. Therefore, it can be proved that the above research is feasible and advanced.

## 5. CONCLUSIONS

In this paper, the application of LED light sources in the lighting design of the city square environment was discussed. Based on the characteristics of LED light sources, the concept of green design was integrated into the design of modern landscape lighting. Then design concept, design principles, design methods and design steps were taken into account. The theoretical support and practical experience were provided for the design of a suitable landscape lighting environment.

Fig.4. Square sculpture lighting

Fig.5. Square waterscape

Fig.6. Square road lighting

Through this study, some conclusions can be obtained as follows: in order to pursue the harmony between LED lamps and environment, in the modern landscape lighting design, it is necessary to take into account the city's humanistic environment in the overall planning of urban environment,

including political, cultural, artistic, scientific, religious, aesthetic and other factors. Outdoor lamps need to expose to the environment for a long time, and the surface treatment must be corrosion resistant. The polyvinyl acetate electrostatic spraying is a good choice. It conforms to the principle of green design, saving energy, environmental protection, pollution-free, and high production efficiency. In addition, it can also achieve a wide range of colours, so that landscape colour planning can have a variety of possibilities. In the connection part of the lamp, the stainless steel fasteners are selected.

Although this paper has achieved good results, there are still some deficiencies because of the limitations of technical development, thus further research will be needed. For example: the poor heat resistance of LED will bring about the problem of short life. In general, the internal temperature of the lamp will be seventy or eighty degrees. To take into account the heat, weight is a problem, while to balance the weight and heat is difficult to guarantee. This is a dilemma in the existing design, and there is no feasible standard.

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Fig.2. PV products in China

Fig.4. Square sculpture lighting

Fig.5. Square waterscape

Fig.6. Square road lighting

Fig.2. Landscape lighting instance

*Yonghong MA, Zhihua ZHAO, and Zhanzhao WANG*

## A Study of the Influencing Factors of the Technological Innovation in Photovoltaic Enterprises

Fig. 1. Crystal silicon photovoltaic cells

*Sumin JIN*

## Operation Modes of Photovoltaic Enterprises and Semiconductor Laser Enterprises Participating in Vocational Education

Fig. 1. Development of vocational education operation mode

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# LANDSCAPE GREEN LIGHTING DESIGN IN URBAN DERELICT LAND BASED ON ECOLOGICAL CONCEPT

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## ABSTRACT

The ongoing urban construction has witnessed more consumption of electricity and lights wear in urban landscape, so green lighting and energy saving have grabbed social attention. Therefore, this paper studies urban landscape green lighting design based on ecological concept. Firstly, a brief introduction of relevant theories and technologies is made, and then taking green lighting, sustainable lighting, illumination technic, selection of energy-saving lights, intelligent lighting design into consideration, this paper summarizes design concepts of urban landscape lighting based on ecological concept. Results show that scientific and healthy urban landscape lighting system is conducive to ecological environment protection and light pollution mitigation.

***Keywords:*** ecological concept, urban landscape, green lighting, design

## 1. INTRODUCTION

Since the twenty-first century, China's urban landscape lighting development has witnessed unprecedented scale and investment. Urban lighting has always been regarded as an important representative of city images, and can bring huge economic and social benefits, so it has attracted attention of the world. However, since the beginning of 2004, a number of cities in China have declared power shortage problems, which brought power resource under the spotlight and urban landscape lighting is regarded as waste of resources. Against this background, energy saving measures in urban lighting design is urgent, and it is high time to carry out green lighting design in urban landscape.

China has always paid attention to lighting energy-saving. In 1996, China's State Economic and Trade Commission held the 96$^{th}$ China green lighting international symposium. Then, the state has issued a series of relevant policies, whose implementation has attracted public attention to green lighting projects [1]. Ecological design concept has just emerged in recent years, which provides theoretical and technical support from architectural design, changing process of landscape design to the production and development of landscape facilities, building materials and lights. [2]. Lighting, to some extent, is the consumption of energy. Ecological landscape lighting can use light to dispel people's fear of dark, which symbols an enjoyable attitude and, moreover, it can use smaller consumption to replace the huge waste in energy consumption in the past, which also meets people's needs for urban landscape beauty [3]. This kind of urban landscape lighting should be more ecological and humane. At present, the pursuit of brightness and high chroma is not conducive to ecological design concept, so designers should not only focus on brightness, but should also pay attention to shadow [4].

Based on the objective requirement of green lighting design of urban landscape controlled by ecological concept, this paper use relevant theories and technologies and summarize design concept of urban landscape lighting based on ecological concept from perspectives of green lighting, sustainable lighting, illumination technology, se-

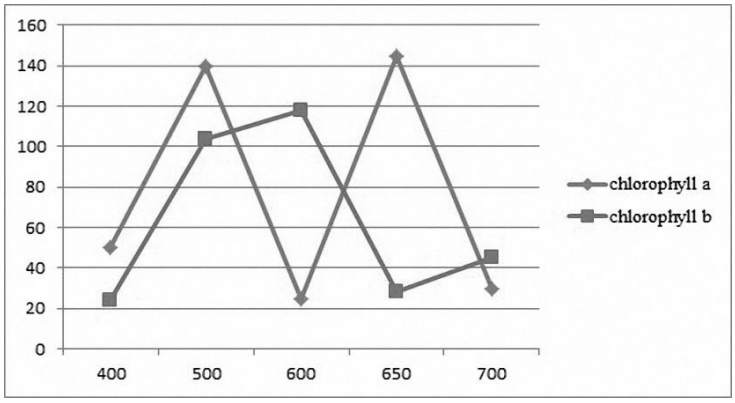


Fig.1. Chlorophyll absorption spectra

lection of energy-saving lights and intelligent lighting design. In the second section, the relationship among green ecological concept, ecology and lighting was expounded. In the third section, the application of sustainable lighting and energy-saving lamps was analyzed, and the design concept of urban landscape lighting based on ecological concept was put forward. In the fourth section, relevant concepts were analyzed and discussed. Finally, in the fifth section, research process and results were summarized.

## 2. STATE OF THE ART

### 2.1. Proposal of landscape green lighting

While light culture formed by modern light sources and lighting has brought a lot of convenience to people, improper use of light sources and unreasonable design of lighting has also caused serious light pollution which affects people's production and life and destroys our ecological civilization. In 1930s, the widespread use of mercury lamp marks the earliest ecological lighting proposal. In 1996, China launched the promotion of green lighting engineering. Green lighting aims developing and promoting energy-saving lighting products, as well as to establish high-quality, efficient, comfortable, safe, and environmentally friendly lighting systems [5]. The basic concept of green lighting is to mitigate environmental pollution caused by electricity generation and reduce resources waste from perspectives of energy saving, reducing consumption and improving the utilization efficiency of solar energy resources. Therefore, landscape lighting's impact on ecological environment can't be ignored [6]. Sustainable lighting is a sustainable lighting concept, whose definition is that sustainable lighting design not only means to meet basic lighting requirements, that is, creating a lighting environment with high quality, but also to minimize artificial lights' impacts on surrounding physical environment [7].

At present, light pollution has become increasingly serious, so the lighting designer must be aware of the seriousness, especially the spill light pollution and night artificial lights' impacts on plants and animals [8]. Studies have shown that lights with different wavelengths have different impacts on photosynthesis of plants. Fig. 1 shows the absorption spectrum of advanced green plants. As can be seen from the graph, different green plants have basically the same absorption spectra, and it concentrates on visible spectrum's blue and violet spectrum ranging from 400 to 600nm, and red and orange spectrum ranging from 600 to 700nm. The horizontal x-axis represents the wavelength, and the y-axis represents the extinction coefficient.

However, in recent years, studies have shown that increase in the amount of ultraviolet radiation will have a great impact on the process of plant growth, mainly causing small-sized leaves and short plants.

### 2.2. The relationship between lighting and ecology

Lighting has a great impact on ecology. For example, in chicken farms, the use of fluorescent lamps with three primary colours to improve chicken farm's brightness and light time can increase egg production rate and in greenhouses, a large day lighting rate can also improve vegetables' yield. From those examples, we can see that lighting can serve us. However, lighting can also have negative impacts on ecology. After being exposed to artifi-

Fig.2. Landscape lighting instance

cial lighting at night, some animals will gradually lose some capabilities in night activities, resulting in problems in self-defense, foraging, reproduction and so on. The bird's migration is an important indicator of ecological environment, but they are most vulnerable to the artificial lights' influences during migration. At night, they rely on natural landscape such as the stars to locate directions, but cities' lighting always makes them get lost [9]. Birds living in cities are dying because of the blurring of seasons. Scientists in Austria have found that a small advertising light box can kill 35 insects a year, leading to the death of a large number of birds because of food shortage, and it can also affect the plant pollination.

In ecology, the reduction of one species will inevitably affect the survival and development of other species. Natural selection can only function in a balanced ecology. Ecology is extremely fragile. Light pollution's grave impacts on plants and animals are bound to pose a threat upon human life in the future. The examples of landscape illumination are presented in Fig.2.

## 3. METHODOLOGY

### 3.1. Research on design methods of urban landscape green lighting

According to different work principles, green lighting's light sources selection in urban landscape can be divided into two categories: solid light sources and gas discharging light sources [10]. General light sources are mainly incandescent lamps, while gas discharging light sources can be divided into arc discharging light source and glow power sources. Arc discharge light sources are mainly fluorescent lamps, while glow discharging source only consists of neon lights. Selection of light source should be considered from aspects of economy, reliability and practicability. Table 1 is a comparison of common light sources' characteristics, power consumption and costs. In that table, *lm/w* stands for luminous efficacy, *K* for (correlated) colour temperature and *h* for service life.

City green landscape lighting not only requires designers to obtain the skilled use of modern lighting technological knowledge, but also to obtain profound artistic accomplishments, so as to be able to accurately grasp the light and colour blend of visual effects, and to create a comfortable and natural feeling [11]. Therefore, in the process of landscape lighting design, several principles should be followed: the efficiency principle, the safety principle, the ecological principle, the humane principle, and the principle of urban cultural characteristics.

In the process of urban landscape lighting design, first of all, the orientation of urban cultural construction should be designed, which is the most fundamental issue. Then, showing methods according to the theme should be confirmed. The development of lighting technology has provided a variety of means and methods for urban landscape lighting. Urban landscape lighting needs to adopt a reasonable quality index design. The main technical quality indicators of the lighting system engineering are as follows: the average illuminance *Er* (lx), the ground average luminance *Lr* (cd/m$^2$), the total uniformity *Vo*, the glare control index *G*, the lighting radius *R*, and so on. In the actual measurement, the following formula can be used.

$$Lr = \frac{Er}{q} = \frac{\varphi \cdot N \cdot UF \cdot K}{q \cdot A},$$

where

*Lr* is an average luminance of pavement, cd/m$^2$;
*Er* is an average illuminance, lx;
*Φ* is luminous flux of a single light source, lm;
*N* is the number of light sources;

**Table.1. Photoelectric characteristics of common electric light sources in landscape lighting**

| Type | *lm/W* | Colour temperature(correlated), *K* | Colour rendering index | Average life span, *h* | Start time | Characteristic |
|---|---|---|---|---|---|---|
| Incandescent lamp | 12 | 2950 | 96 | 1000 | Instantaneous | Easy to install and use; immediate start and low cost |
| Tungsten halogen lamp | 25 | 2800 | <95 | 2500 | Instantaneous | Small size; high brightness; light colour is white; easy to install |
| Fluorescent lamp | 80 | 6600 | 70–80 | 6500 | A few seconds | Colour variety; high intensity and taking into account the economy |
| Low-pressure sodium lamp | 200 | 1900 | 20 | 16000 | 8–10min | High efficiency, long service life and poor colour rendering |
| High-pressure mercury lamp | 60 | 5500 | 30–40 | 20000 | <6min | High efficiency; long service life; appropriate colour rendering |
| High pressure sodium lamp | 120 | 2100 | 30 | 24000 | <20min | High efficiency; long service life; colour rendering |
| Xenon lamp | 25 | 6000 | 94 | 1000 | <20min | The environmental requirements are not high; spectral analysis and eye approach |
| Metal halide lamp | 100 | 5500 | 60–95 | 10000 | 15min | High efficiency; long life; good colour rendering |
| The neon lights | 10 | - | - | above 15000 | Instantaneous | Modelling is rich; colour is gorgeous; one time modelling; installation technology is complex; fragile |

*UF* is luminous flux utilization coefficient;
*K* is the lamp maintenance index;
*A* is the lighting area, $m^2$;
*q* is average illumination coefficient.

In terms of the landscape lighting design, in recent years, the widely-used LED lights, solar lights, optical fibre lamps are all new-style lamps and lanterns. However, due to limitations of high costs and lack of technologies, the use rate of new lighting products in the market is not high. However, it is undeniable that the new lighting products can provide a better space for the development of light culture.

### 3.2. The development trend of green lighting design in urban landscape

With accelerated pace of urbanization in China, the development trend of green lighting design in urban landscape will be carried out in the form of cross-field design, which refers to cooperation between two or more than two different fields, and it contains innovation principles. The most basic idea that designers should have is the concept of innovation, and this innovative way of thinking makes the design itself has to have a strong vitality, so it is also continuous. Crossover design, Fig.3,

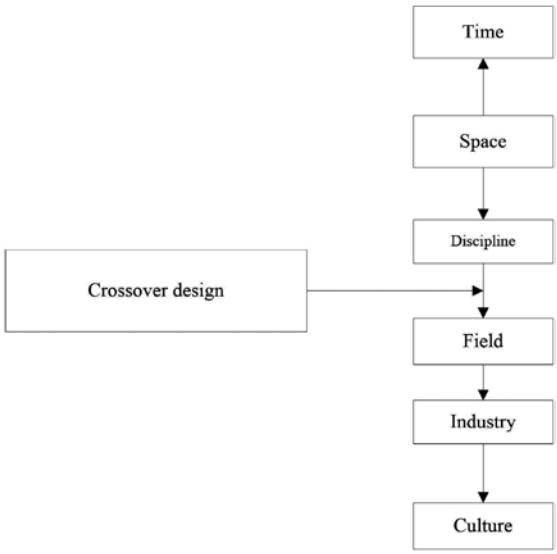


Fig.3. Scope of the crossover

is a new way of life and aesthetic attitude, and it has set off a strong storm in the design field. Its biggest feature is that it integrates unrelated elements to form a brand-new idea. Therefore, cross-field design is multidisciplinary and interactive. Among them, the city lighting sculpture is a kind of cross-field design.

Lighting design can also be described as light environment design, which requires the combination of technology and art. On the whole, the light environment includes satisfying sensory feelings, creating artistic atmosphere and conducting interaction between human and environment. Therefore, the lighting design not only includes scientific, technologic fields but also cultural and economic fields, so it is a comprehensive and compatible system.

Under the innovative development trend of urban landscape green lighting, how to better carry out the work of urban green lighting energy saving is also extremely important. In this paper, there are pointing out three aspects. Firstly, selection of energy-saving light sources and lamps should be taken seriously. Good light source can save more power resources, such as LED lamp. LED technology can save a lot of energy. Secondly, effective measures can be taken to reduce extra power in the lighting process. A large portion of the energy is consumed in the lighting circuit because of the resistance of the wire. In order to solve this problem, capacitors can be installed to enhance the active power and reduce the inactive power. Thirdly, urban landscape lighting and other maintenance measures should be strengthened. Each light source has its own operational life span, so timely replacement of light sources is conducive to light environment's natural comfort and aesthetics.

Under ecological concept, the city lighting should consider integrity and make plans according to cities' own characteristics. Different methods should be used in different places, such as brightness of the lights, different atmosphere, different styles, and so on. In terms of derelict lands in cities, softer and more energy efficient sculptures or lamps can be used to show the charm of the city but cannot dwarf cities' charm. Moreover, we should select appropriate spectrum to promote the absorption of pigment, thereby promoting the growth of plants.

## 4. RESULT ANALYSIS AND DISCUSSION

Ecological environment is a whole organic system with various factors and conditions. Therefore, in the process of designing city lighting, we should view the concept of green lighting under the control of ecological concept from modern science and technology aesthetic perspectives, and follow art and design principles, so as to design aesthetic lighting which can meet social development requirements and meet environmental requirements of arts. At the same time, landscape lighting should respect nature, as well as the nature of its own development and evolution characteristics. Designers should accurately grasp nature's characteristics, so as to design a light environment in line with natural characteristics, and bring people the enjoyment of natural and comfortable light culture. In addition, the intervention of the environment should be minimized. Urban landscape lighting will extend humans' activities, which is bound to interfere with the environment or some damages to the environment. If the least intervention can be achieved, then nature will coexist with continuous lighting.

In order to verify the feasibility and reliability of the above models, corresponding practical measurement work was completed. As can be seen from Table 2, under different parameters and different lights placement, there is different uniformity. The strength of LU varies with the variation of line parameters. A larger average means better quality.

Several widely-used methods in designing urban landscape green lighting are as follows. The first is upward lighting, which means lamps will project upward and illuminate objects. The second is downward lighting, opposite to upward lighting.

**Table 2. Landscape lighting lamps and lanterns is reasonable position distribution table**

| Lighting pattern | Height of luminaire | Light pole difference between | LU2 | LU4 | LU6 | Remark |
|---|---|---|---|---|---|---|
| Unilateral arrangement | 6/12 | 15–18/32–36 | 17/4 | 35/9 | 53/13 | Good uniformity |
| Central symmetry | 8/10 | 20–24/25–30 | 10/6 | 20/12 | 30/18 | |
| Lateral suspension cloth | 8/14 | 20–24/36–42 | 11/4 | 23/8 | 34/11 | Good uniformity |
| Bilateral | 12 | 32–36 | 10 | 21 | 30 | |

The third is contour lighting, which means outlines of the illuminated objects are highlighted by lights. The fourth is back lighting or silhouette lighting where trees are in the dark, and the wall behind trees is illuminated by a uniform light, thus forming a contrast light. The fifth is moonlight lighting where lights on trees are divided to shoot upward and downward. Under the guidance of ecological concept, according to relevant principles, urban landscape green lighting design will be further developed.

In accordance with the above principles and methods, under the guidance of the ecological concept, combining landscape characteristics and urban cultural characteristics, a simulation figure of landscape lighting in line with the sustainable concept was designed, as shown in Fig. 4.

This scheme starts from green and sustainable illumination, combines design methods of lighting technology and selection of energy-saving lamps and intelligent lighting, and puts forward concept of green landscape design in urban derelict land in line with ecological concept.

Lighting design can also be described as light environment design, which requires the combination of technology and art. On the whole, the light environment includes satisfying sensory feelings, creating artistic atmosphere and conducting interaction between human and environment. Therefore, the lighting design not only includes scientific, technologic fields but also cultural and economic fields, so it is a comprehensive and compatible system. In the short-term or long-term, cities' landscape must focus on energy-saving and developing of the natural and comfortable directions.

## 5. CONCLUSIONS

With the development of social economy in the field of landscape lighting, people's demands aren't focusing only on illumination, but also require energy-saving and safe green lighting. Sustainable lighting has emerged along with ecological theories. Nowadays, cities need a bright, beautiful and elegant, natural and comfortable light cultural atmosphere, but they should also focus on energy-saving and light pollution mitigation. Based on this, this paper studies green lighting design in urban landscape based on ecological concept. This paper use relevant theories and technologies and summarize design concepts of urban landscape lighting based on ecological concept from perspectives of green lighting, sustainable lighting, illumination technology, selection of energy-saving lights and intelligent

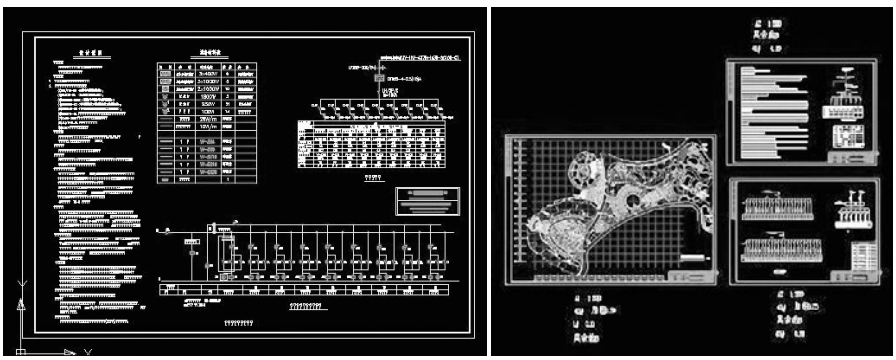

Fig.4. Urban landscape lighting design model

lighting design. The urban landscape green lighting is not only about light source material selection, but also about artistic designs in line with urban cultural characteristics. A scientific and healthy urban landscape green lighting construction system is conducive to technological environment protection and light pollution mitigation. It is hoped that these conclusions can provide theoretical guidance for future researches on green lighting design in urban landscape.

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# THE CORRELATION ANALYSIS OF SOCIAL RESPONSIBILITY AND CORPORATE PERFORMANCE OF LIGHTING CORPORATIONS

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**ABSTRACT**

With the development of economy, the reputation of corporations is paid more and more attention to, which is mainly reflected in consumers' wishes for purchasing corporate goods, and it's considered to be an intangible competitive advantage, resulting in social responsibility marketing. To this end, the analysis of correlation between social responsibility and corporate performance of lighting corporations can help to promote the fulfilment of social responsibility and to implement the sales plan. Firstly, the relationship between social responsibility and corporate performance of lighting corporations was analyzed, and the index system was constructed; then, the relationship between social responsibility and the corporate performance was obtained by a factor analysis; finally, the fact that the fulfilment of social responsibility of corporations was directly related to the financial performance of the corporate and had a positive impact was established.

**Keywords:** lighting corporation, social responsibility, corporate performance, correlation analysis

## 1. INTRODUCTION

With economy constant development, the social responsibility of corporations has gradually extended on many countries, and since the beginning of 2006, it has gotten wide attention [1]. Although a corporation is an independent unit, it is closely related to the interests of the public, government and other related institutions. In particular, in the twenty-first century, the demands of social groups for corporate social responsibility are increasing. Whether the corporation should take on a social responsibility or not, what responsibilities it should shoulder, what effects will be for business management, and other issues have become the focuses of economic studies and of business [2].

On the one hand, a corporation, as a social institution, enjoys the rights granted by society and must fulfil its obligations; on the other hand, the fulfilment of social responsibilities of modern corporations is directly related to the brand, reputation and other important intangible assets of corporations, which not only will have a significant impact on the financial performance, but also determine the rise and fall of corporations [3]. The social responsibility of corporations needs to pay corresponding costs, which will obviously affect the corporations' short-term interests' maximization. The process of fulfilling the social responsibility of the corporation increases the non-business-related invested cost and consumes corporate resources, which may reduce the competitiveness of the corporation in its core business and put it at a disadvantage in competing with other corporations [4]. But from a long-term perspective, it can't be said that the investment in the corporation's social responsibility doesn't make sense. A long-term strategic investment of the corporation can eliminate corporation's potential risks, improve its social popularity and play a positive role in the long run. Although the investment in social responsibility can't be di-

rectly expressed by performance improvements, it can provide corporations with core competitiveness and social influence, which can achieve long-term profitability [5].

The fulfilment of a lighting corporation social responsibility is directly related to the quality of the green and sustainable development environment of the society and the improvement of people' living quality. Therefore, with the promotion of public awareness of energy conservation, people begin to pay more and more attention to the performance of lighting corporations, hoping to contribute to public supervision and play a positive role for smooth implementation of lighting corporations' social responsibility. This paper's aim is to study and analyze the relationship between the social responsibility of corporations and the corporate performance in the context of understanding and analyzing the current social responsibility of corporations.

## 2. STATE OF THE ART

### 2.1. Social responsibility of corporations

According to the social responsibility of corporation's standards, corporation operators have an obligation to meet various needs both inside and outside the industry, rather than simply pursue the sales profit maximization [6]. The concept of social responsibility of corporations emerged in 1920s. In the early twenty-first century, the social responsibility of corporations has become the focus of social network media and the world. Today, market competition between corporations and brands is becoming more and more intense, and issues and reports on the social responsibility behaviour of corporations in the media, public, society, market participants, and government departments are gradually increasing. But different social actors have different interpretations of the social responsibility of corporations, which are self-contained [7]. From corporations' point of view, corporate executives believe that the core of corporate performance appraisal is the growth of profits, which is also the ultimate and important goal of corporate management. Only the profit maximization can stimulate the growth of the corporate performance, and the social responsibility of corporations doesn't produce economic benefits after all. From a social point of view, the public believes that, as a part of society, a corporation should give feedback to the public, and the society is the focus of the corporation. Consumers are more conservative about these two opposing views, and they don't think it's wrong to pursue their own interests, but they are more inclined to organizations that fulfil their social responsibility [8].

### 2.2. Research status of the social responsibility of corporations

Corporate social responsibility was proposed by American scholar Sheldon in 1924, and this theoretical system was universally applied in the west at the end of the twentieth century [9]. At present, scholars in China and abroad have carried on scientific and systematic theoretical exploration around the basic connotation of the theory, the related sociological theory, the social responsibility system, the promotion way and so on. At present, a relatively high degree of corporate social responsibility research system has been established [10]. After the subprime mortgage crisis in the United States, the world re-examined and re-summarized the problems of corporate social responsibility: corporations are made up of many citizens, so they should have a social responsibility. Many multinational companies promote their social responsibility as the main way to improve their comprehensive competitiveness, and many European and American countries regulate the social behaviour of corporations through the promulgation of laws and regulations and other coercive means. In November 2010, an international standard on social responsibility was put forward, and the International Organization for Standardization (ISO), as well as the Global Continuity Reporting Institute (GRI) developed social responsibility guidelines (ISO26000), which were widely accepted and adopted because of their more complete content, normative standards and higher degree of practicality [11]. The global social responsibility movement has also promoted Chinese scholars' research on the value, significance and practice of social responsibility [12]. At present, most of small and medium corporations in the society have been aware of the importance of social responsibility for improving the value of the corporation, demonstrating its own development planning and environmental determination and getting good economic returns and social support by reporting business operations and sustainable development planning to the community [13].

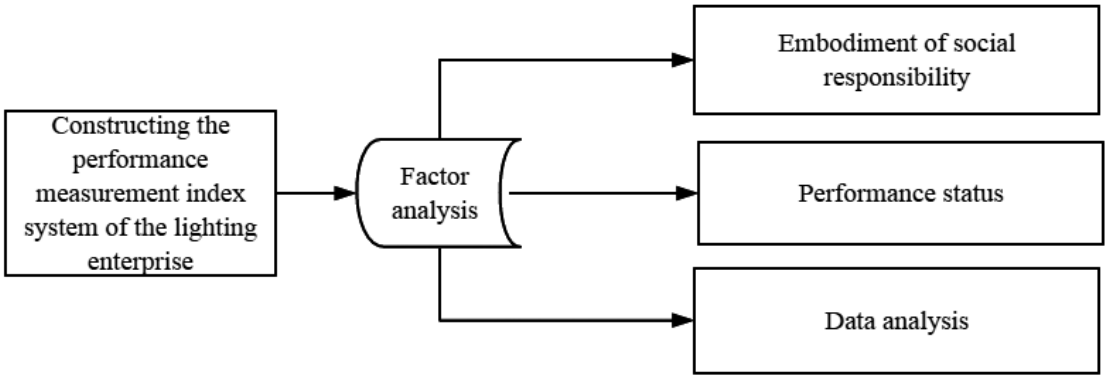


Fig.1. Process of constructing the performance measurement index system of lighting corporations

## 3. METHODOLOGY

The construction of an index system must follow the following principles: the first one is the scientific principle, which means that a new index system shouldn't be blindly established, and must be based on previous studies, taking the impact of income, profit growth, social evaluation and other factors of lighting corporations into consideration, and making scientifically integrated classification to ensure that measurable results of the established index system are with a high degree of credibility.

The second one is the feasibility of the principle. When establishing the measurement index system of lighting corporations' performance under social responsibility, we have to analyze the feasibility of this index system. From the previous scholars' research materials, there are more factors and directions in the implementation and development of corporate social responsibility to be investigated, and the results of social responsibility measurements are also more diverse. Therefore, in order to ensure the accuracy of data analysis, the selection of sample data comes from the network access.

The third one is the principle of comprehensiveness. There are many factors determining the level of corporate performance, including geographical factors, industrial types, industrial upgrading, industrial agglomeration and local consumption and living standards. Therefore, we must take into account the factors above in the selection of indicators, so that the results of the analysis will have more practical significance. The process of constructing the performance measurement index system of a lighting corporation is shown in Fig. 1.

Corporate social responsibility is mainly reflected in the quality of services provided to consumers, and this quality will directly affect the performance of the corporation and its operating profit. Therefore, the main factors of corporate social responsibility could be summed up as follows: customer trust, green lighting marketing, sales service evaluation of energy-saving lighting, after-sales service evaluation, and the overall impression of the lighting corporation. The performance is related to a number of consumptions, and thus is marked by customers' frequency of shopping. In this study, the factor analysis method was used to establish the performance measurement index system; then, the corresponding measurement model was established, and the factor analysis was applied to empirical analysis and research on acquired data such as performance and social responsibility [14]. The factor analysis is an extension of the principal component analysis, which requires that the sample value is larger than the value of the variable; it can be used for the correlation analysis of multiple influencing factors in the sample data. Moreover, since the majority of the variables in the principal component are strongly correlated, the variables in the principal component can be represented by the relationship between some factors, which can not only represent the relationship between the original variables in the principal component, but also represent the relationship between factors [15]. In addition, the analysis method can also solve the problem of dimensionality reduction in the process of multivariate statistical analysis, and classify the variables of different factors.

The specific steps of the factor analysis were as follows: the first step was to standardize the original data. As the difference of the quantity index of the original measurement index data brought great difficulty into the comparison between the indexes, with the help of the transformation method different dimensional indexes were transformed into dimen-

**Table 1. Performance measurement index system under social responsibility**

| Index type | Index name | Index code | Unit |
|---|---|---|---|
| Embodiment of social responsibility | Customer trust | X1 | - |
| | Lighting green marketing | X2 | 0/1 (know/ don't know) |
| | Evaluation of customers' sales service for energy saving lighting | X3 | 1–4 |
| | Evaluation of the returned service | X4 | 1–4 |
| | The overall impression of the lighting enterprise | X5 | 1–5 |
| Performance status | Frequency of customer shopping | X6 | Times per week |

**Table 2. Social responsibility marketing performance indicators of lighting corporations**

| Number | X1 | X2 | X3 | X4 | X5 | X6 |
|---|---|---|---|---|---|---|
| 1 | 7.00 | 0.00 | 3.00 | 3.00 | 4.00 | 2.00 |
| 2 | 8.00 | 0.00 | 1.00 | 4.00 | 5.00 | 3.00 |
| 3 | 8.00 | 0.00 | 1.00 | 4.00 | 4.00 | 3.00 |
| 4 | 6.00 | 0.00 | 1.00 | 3.00 | 3.00 | 2.00 |
| 5 | 8.00 | 0.00 | 4.00 | 4.00 | 4.00 | 2.00 |
| 6 | 5.00 | 0.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| 7 | 7.00 | 0.00 | 2.00 | 3.00 | 4.00 | 2.00 |
| 8 | 8.00 | 0.00 | 1.00 | 4.00 | 4.00 | 2.00 |
| 9 | 8.00 | 1.00 | 1.00 | 4.00 | 5.00 | 4.00 |
| 10 | 7.00 | 0.00 | 4.00 | 3.00 | 4.00 | 2.00 |
| 11 | 8.00 | 0.00 | 1.00 | 4.00 | 4.00 | 2.00 |
| 12 | 7.00 | 0.00 | 4.00 | 4.00 | 4.00 | 2.00 |
| 13 | 7.00 | 0.00 | 2.00 | 3.00 | 3.00 | 2.00 |
| 14 | 7.00 | 1.00 | 4.00 | 4.00 | 5.00 | 2.00 |
| 15 | 8.00 | 0.00 | 1.00 | 4.00 | 4.00 | 4.00 |
| 16 | 6.00 | 0.00 | 2.00 | 3.00 | 3.00 | 2.00 |
| 17 | 8.00 | 1.00 | 4.00 | 4.00 | 5.00 | 4.00 |
| 18 | 7.00 | 0.00 | 1.00 | 4.00 | 3.00 | 2.00 |
| 19 | 7.00 | 0.00 | 4.00 | 3.00 | 3.00 | 2.00 |
| 20 | 7.00 | 0.00 | 1.00 | 3.00 | 4.00 | 2.00 |

sionless index data, which made them standardized and derived the correlation coefficient of the sample data matrix R. The second step was the Kaiser-Meyer-Olkin (KMO) test. As the third step, the eigenvalues and eigenvectors of the pairwise comparison matrices constructed above were found, and according to the weight of different factors and the eigenvectors obtained, the factor weight matrix was constructed. In this experiment, the common factor with the accumulating contribution rate of 80 % was selected, and the commonness was explained. As the fourth step, the factor weight matrix obtained at

**Table 3. Standardized index values**

| Number | X1 | X2 | X3 | X4 | X5 | X6 |
|---|---|---|---|---|---|---|
| 1 | –0.53055 | –0.23995 | –0.40945 | –0.40945 | 0.6052 | –0.82375 |
| 2 | 0.79582 | 0.9598 | –0.40945 | –0.40945 | –0.9078 | 0.82375 |
| 3 | 0.79582 | 0.9598 | –0.40945 | –0.40945 | –0.9078 | 0.82375 |
| 4 | –0.53055 | –1.4397 | –0.40945 | –0.40945 | –0.9078 | –0.82375 |
| 5 | –0.53055 | 0.9598 | –0.40945 | 2.3202 | 1.3617 | 0.82375 |
| 6 | –0.53055 | –2.63944 | –0.40945 | 2.3202 | –0.1513 | –2.47126 |
| 7 | –0.53055 | –0.23995 | –0.40945 | –0.40945 | –0.1513 | –0.82375 |
| 8 | –0.53055 | 0.9598 | –0.40945 | 2.3202 | –0.9078 | 0.82375 |
| 9 | 2.12219 | 0.9598 | 2.3202 | –0.40945 | –0.9078 | 0.82375 |
| 10 | –0.53055 | –0.23995 | –0.40945 | –0.40945 | 1.3617 | –0.82375 |
| 11 | –0.53055 | 0.9598 | –0.40945 | –0.40945 | –0.9078 | 0.82375 |
| 12 | –0.53055 | –0.23995 | –0.40945 | –0.40945 | 1.3617 | 0.82375 |
| 13 | –0.53055 | –0.23995 | –0.40945 | –0.40945 | –0.1513 | –0.82375 |
| 14 | –0.53055 | –0.23995 | 2.3202 | –0.40945 | 1.3617 | 0.82375 |
| 15 | 2.12219 | 0.9598 | –0.40945 | –0.40945 | –0.9078 | 0.82375 |
| 16 | –0.53055 | –1.4397 | –0.40945 | –0.40945 | –0.1513 | –0.82375 |
| 17 | 2.12219 | 0.9598 | 2.3202 | –0.40945 | 1.3617 | 0.82375 |
| 18 | –0.53055 | –0.23995 | –0.40945 | –0.40945 | –0.9078 | 0.82375 |
| 19 | –0.53055 | –0.23995 | –0.40945 | –0.40945 | 1.3617 | –0.82375 |
| 20 | –0.53055 | –0.23995 | –0.40945 | –0.40945 | –0.9078 | –0.82375 |

the third step was rotated by the maximum orthogonal rotation, then the orthogonal factor weight matrix was obtained, and the internal factor was renamed. As the fifth step, according to the previous step, the orthogonal rotation matrix was obtained.

This paper takes a lighting corporation in Guangzhou as an example, and the corresponding performance measurement index system constructed under social responsibility is as shown in Table 1.

The frequency of customer shopping is as follows: often, once a week, shopping during sales promotions and seldom, which are manifested by 4, 3, 2 and 1 respectively.

The creditability is quantified as 5, 6, 7 and 8.

Whether the customers understand the green lighting marketing or not: 1 means yes, 0 means no.

The evaluation of sales service: helping customers to solve the problems in the process of purchase, responding very quickly to the consultation, timely solving customer complain, not providing good service, which are marked as 4, 3, 2 and 1 respectively.

The evaluation of service of changing or refunding: good service attitude, general, very troublesome, bad attitude, no one to solve, which are marked as 5, 4, 3, 2 and 1 respectively.

The general impressions of the lighting corporation: very satisfied, satisfied, general, not satisfied, extremely dissatisfied, which are marked as 5, 4, 3, 2 and 1 respectively.

## 4. RESULTS ANALYSIS AND DISCUSSION

In this study, the data were derived from the network questionnaire, and the relevant data were selected according to the seven indexes established above. The consumers of different lighting corporations were analysed by correlation calculus, and the data above were sorted (as shown in Table 2).

**Table 4. Correlation matrix**

| | X1 | X2 | X3 | X4 | X5 | X6 |
|---|---|---|---|---|---|---|
| X1 | 1 | 0.536 | 0.534 | –0.229 | –0.19 | 0.46 |
| X2 | 0.536 | 1 | 0.241 | –0.103 | –0.086 | 0.832 |
| X3 | 0.534 | 0.241 | 1 | –0.176 | 0.261 | 0.355 |
| X4 | –0.229 | –0.103 | –0.176 | 1 | 0.043 | –0.118 |
| X5 | –0.19 | –0.086 | 0.261 | 0.043 | 1 | –0.066 |
| X6 | 0.46 | 0.832 | 0.355 | –0.118 | –0.066 | 1 |

**Table 5. Eigenvalue (greater than 1) and variance contribution rate**

| Principal factor number | Characteristic value | Variance contribution rate | Cumulative variance contribution rate |
|---|---|---|---|
| 1 | 3.318 | 47.404 | 47.404 |
| 2 | 1.243 | 17.753 | 65.157 |
| 3 | 1.016 | 14.511 | 79.668 |

As the difference of the quantity indexes in the original measurement index data make the comparison between the indexes extremely difficult, with the help of SPSS data analysis software, the indexes of different dimensions were converted into dimensionless index data, which made it standardized. The standardized values of each index are shown in Table 3.

A data analysis tool (SPSS16.0 software) was used for factor analysis to obtain the correlation matrix, as is shown in Tables 4 and 5.

By means of SPSS data analysis software, the correlation coefficient matrices as well as the eigenvalues, variance contribution rate and cumulative variance contribution rate constructed by the seven indicators which represent the performance of lighting corporations could be gained. From Table 3, there are three main factors with eigenvalues being greater than 1. These three main factors were named Y1, Y2 and Y3, and the cumulative variance contribution rate of these 3 main factors was 79.68 %. And then, the factor weight matrix obtained by orthogonal rotation was used to analyse the marketing performance of corporate social responsibility and the main factors of social responsibility marketing (see Table 6).

From Table 5, the main factor Y1 has a heavier weight in the creditability score (X2) and evaluation of the service of goods returning (X6), which shows that the performance under lighting corporations social responsibility is affected by customer's trust and the service of goods return. Therefore, the main factor Y1 can be named as customer service. Secondly, the main factor Y2 has a heavier weight in such two indicators as the understanding of green marketing of energy-saving lamps (X3) and the evaluation of sales services (X5), which can properly reflect that lighting corporations need to improve performance from sales service quality and green marketing. So Y2 can be named social responsibility sales service factor. The main factor Y3 has a heavier weight in such two indicators as customer shopping frequency (X1), and the social image of lighting corporations, that is, the overall impression (X7), so Y3 can be used to represent customer'

**Table.6.The factor weight matrix obtained by orthogonal rotation**

| | Y1 | Y2 | Y3 |
|---|---|---|---|
| X2 | 0.935 | –0.074 | –0.026 |
| X6 | 0.908 | –0.004 | –0.009 |
| X7 | 0.822 | 0.311 | 0.265 |
| X1 | 0.653 | –0.044 | 0.456 |
| X5 | –0.115 | 0.913 | –0.143 |
| X3 | 0.443 | 0.598 | 0.416 |
| X4 | –0.022 | 0.034 | –0.894 |

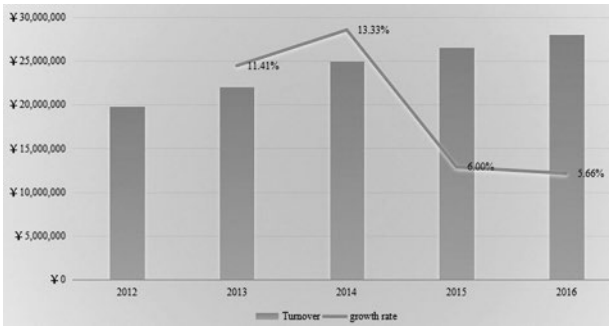


Fig.2. Turnover of lighting corporations in recent years

evaluation on lighting corporations. In summary, it is found that the better the social responsibility of lighting corporations is implemented, the higher the evaluation of social consumer group impressions will be. Thus, the stimulating of consumption and improving it can be implemented from the pre-sale, sale and after-sales service.

The turnover of lighting corporations in recent years is shown in Fig. 2.

Based on the analysis above, it can be concluded that the social responsibility of lighting corporations is closely related to the corporate performance, and the corporate performance is affected by the fulfilment of corporation social responsibility. And the survey shows that the lighting corporation, that was the research object, had a good fulfilment of social responsibility from 2012 to 2016, and its turnover and corporate performance were under continuous improvement, especially between 2012 and 2013, with the growth rate being at the top.

## 5. CONCLUSIONS

With current continuous progress, the economy will also gain rapid development. However, the rapid development of the economy has its negative aspects as well. The influence of the concept of green sustainable development on society and people's life is also becoming more and more serious. For the lighting industry, the corporations' impact on the environment and ecological damage is greater and more likely to have a negative impact on society, so corporations should pay more attention to the fulfilment of social responsibility. First of all, such relevant theories as social responsibility, and social responsibility of lighting companies in particular, were introduced; then, the data model was constructed through the performance measurement index system with the factor analysis method, and SPSS software was used to rotate and analyse the data; finally, it was concluded that there was a strong correlation between social responsibility and corporate performance of a lighting corporation in Guangzhou. The better the fulfilment of the social responsibility is, the higher the annual sales and performance of a corporation will be. Although the fulfilment of social responsibility at this stage can be a strong explanation of the positive impact on performance, corporations shouldn't be addicted to good implementation of the social responsibility in the past and ignore the current commitment and fulfilment of the social responsibility. Relevant departments at all levels should establish the theory of corporations social responsibility, evaluation system and management methods that are suitable for China's current national conditions and can be widely accepted by lighting corporations.

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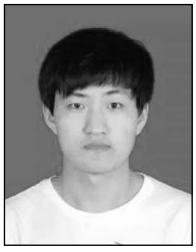

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# OPERATION MODES OF PHOTOVOLTAIC ENTERPRISES AND SEMICONDUCTOR LASER ENTERPRISES PARTICIPATING IN VOCATIONAL EDUCATION

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**ABSTRACT**

At present, China's economic development comes with a price of large consumption of resources and energy that exerts a great impact on the ecological environment. By analyzing the main influencing factors of operation mode of photovoltaic enterprises and semiconductor laser enterprises participating in the vocational education, this paper finds that the key factor is the improvement degree of the internal links within industries in an attempt to provide some theoretical basis and scientific support for the promotion and perfection of the mode of vocational education in China.

**Keywords:** photovoltaic enterprise, semiconductor laser enterprise, vocational education, operation mode

## 1. INTRODUCTION

With the rapid development of the world economy, the world witnesses both a great development and progress of multiple industries and huge resource consumption. Since the industrial revolution, countries around the world have begun to develop from traditional agricultural economy to industrial economy [1]. The rapid economy development requires a large amount of resources and energies, which boosts an increasing application of relevant developing technologies in real life. However, short-term and non-renewable resources such as fossil fuels that had been formed for a long time can't recover quickly after huge consumption, thus causing the crisis of resource shortages and other serious problems [2]. Moreover, due to the burning and extensive use of traditional resources the resulting greenhouse gases cause the so called greenhouse effect, that leads to a changing ecological environment, sea level rises and a decreasing population of original species, and as a result damages the earth's ecosystem. In addition, the use of traditional energy and resources may also cause environmental pollution such as air and water pollution that affects people's health and harms friendly environment and sustainable development. And the sustainability of China's economic development will also suffer [3]. Therefore it is urgent to find alternative new energy sources, and now it has gradually become the inevitable trend of developing and utilizing new energy. And the problem of how to get new energy and how to effectively operate and manage new energy development enterprises have become one of the most important subjects of contemporary researches. Driven by the economic development and the pressure of this era, people begin to study and apply some new energies in our production and life. These new energies come from natural light and other substances that are clean and sustainable. Today there are many new energy technologies applied in real life that not only effectively ease the current energy shortage, but also reduce the traditional pollutant emissions and maintain natural resource efficiency [4]. Today photovoltaic (PV) and semiconductor laser (SL) technology has attracted people's attention as applications of new energy. Furthermore, due to the advanced concept

of resource efficiency and sustainability of the two industries, there are burgeoning enterprises thriving in this field.

The new energy industry with high-speed development has gradually attracted the attention of China's education system [5]. Personnel cultivation can help PV companies and SL enterprises to improve their development theory and upgrade their comprehensive power, which requires developing relevant vocational institutions. Furthermore, it also needs some support to secure the progress of the enterprises [6]. Since the reform and opening up, a lot of vocational institutions in China have been established and have played a positive role in cultivating relevant technical talents in China. At the early stage of the vocational colleges establishment, because of the independence of different levels of college schooling, colleges were more of a planned economy that could not meet the real demand and keep up with the time, leading to a poor teaching performance [7]. However, with the global economic development some changes are made in China's society and economy such as a more diversified social industrial structure and a more complete industrial chain. Therefore, in order to better adapt to the status quo of China's rapid economic development, it is of top priority for China's education field to cultivate professional talents. The traditional vocational physical education concepts cannot fit in with the current need for cultivating professionals with high qualification. Therefore, it is extremely necessary to find a management way to regulate the operational mode of vocational education (VE) [8]. Under this background, China's VE operation mode witnesses a certain development, and its cooperation with relevant business begins to increase. Moreover, due to the increasing emphasis on VE and the increasing investment of government funds, the operation mode of VE in China gradually becomes more rational and systematic. However there are still many shortcomings and defects. By analyzing the operation mode of PV and SL enterprises participating in the VE and the integration of the VE operation mode with business, this work provides a theoretical basis and scientific support for improving the VE system in China, Fig. 1.

Fig. 1. Development of vocational education operation mode

## 2. STATE OF THE ART

### 2.1. Status of domestic and foreign PV and SL enterprises

Today's world gradually enters into the era of industrialization, which brings much convenience and many innovative products, and changes our lifestyle. However, there are many uncoordinated phenomena in the trend of world rapid economic development. The rapid development of the economy requires a lot of energy and resources, and such huge resource and energy consumption leads to the decline of world's resource reserves. In addition, due to the inevitable waste, the shortage of resources has become one crisis affecting the sustainable development in the contemporary era. What's more, the massive use of traditional energy has endangered the world living environment with such effects as serious environmental pollution and declining biodiversity. Moreover, serious pollution causes frequent diseases and threatens people's life security [9]. For example, though blessed with vast land area and abundant resources reserves, China is backward in resource development and has serious resource waste because of relatively lagging-behind resource development technology and poor production technology in some sectors. In addition, due to a China's large population, its per capita share of resources and energy is below the world average. It is reported that the duration of China's resource development will not last for a long time because of huge annual resource consumption despite a large resource reserve. Moreover, since the beginning of the new century China's great economic growth has brought much convenience to people's life, but at the same time it also causes some harms such as inimical materials like $SO_2$, $CO_2$ and dust emitted in quantities that exceed the maximum environmental capacity and result in a series of environmental problems that in turn threatens China's economic development. Such a problem is salient

in Northern China due to the heating system [10]. It has become the main trend in this era to develop some new sustainable energy. And PV and SL enterprises become key industry in today's world because of the utilization of sustainable and renewable energies such as natural light that eases the environmental pollution caused by the burning of traditional energy sources. Today, products of PV industry and SL industry have been gradually applied to various industries and people's production and life. In addition, a large-scale application of products has also promoted a further development of relevant industries, and creates a win-win situation in the industry and world economy due to its energy-saving and emission-reducing effects.

### 2.2. VE operation mode

With the advent of the industrial revolution, more and more workers with advanced skills are required in the industrialized development so as to inject more vitality into traditional enterprises. And this demand is increasing with the deepening of the industrialization that drives up an increasing demand on the operation mode, influence and schooling of VE [11]. Nowadays, many countries and regions in the world begin to pay more and more attention to the development of VE institutions, Fig. 1, and adjust their teaching physique and model. Improvement is made on the relevant theory that creates a great impetus for the appropriate professional personnel training and a great practical value for the world overall economic development [12]. Since the reform, China's economy has developed rapidly. However, there's a disjunction between the high-speed economic development and the traditional VE, making the VE operation mode unable to satisfy the demand within all sectors and enterprises for high-level personnel and further resulting in waste of human and teaching resources [13]. Nowadays it has become the main topic of research in the world in this area to find ways to increase the role of VE in economic development and maximize its educational value though reforms of its operation mode, which will also stimulate VE institutions to examine and improve themselves so as to generate a positive effect for the economic development.

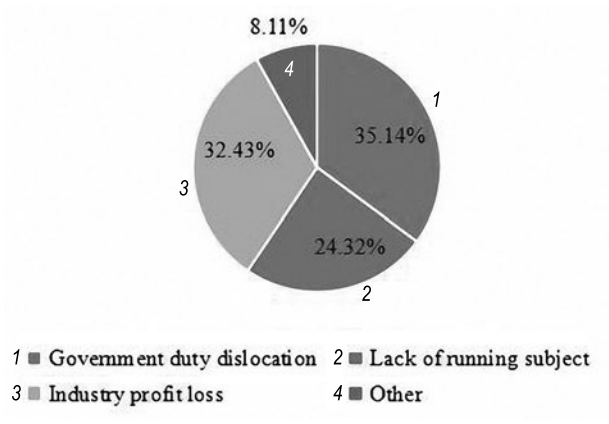


Fig. 2. Current ooperation mode of PV and SL enterprises participating in the VE in China

## 3. METHODOLOGY

### 3.1. Current operation mode of PV and SL enterprises participating in the VE in China

China's demand for new energy has promoted development of many new energy industries such as PV and SL enterprises which enhance China's comprehensive economic strength and calls for more professional personnel in this field. Therefore, it drives China's VE to cultivate relevant personnel [14]. Today China's vocational institutions strengthen their emphasis on the cooperation with business entities, which makes the school-enterprise cooperation to become the mainstream VE model. However, there is still a certain obstacle in the process and system of enterprises participating in the VE because the cooperation solely relies on private relations or government's mandatory instructions [15]. These deficiencies and defects of the VE operation mode in China are reflected in different aspects including the government responsibility, the main body of schooling and the interests of the industry, as shown in Fig. 2.

### 3.2. Analysis of the operation mode of PV and SL enterprises participating in the VE in China through factor analysis model

Firstly, according to literature review, this work determined and summarized main influencing factors of the operation mode of PV and SL enterprises participating in VE, as shown in Table 1.

Secondly, the degree of information inclusion between indicators is determined according to Pearson correlation analysis of all indicators which improves the accuracy of this work.

Finally this work divides the evaluation scores of all primary indicators, and the highest scores are

**Table 1. Influencing factors of the operation mode of PV and SL enterprises participating in VE**

| Variable | Index content | Number |
|---|---|---|
| Governmental duties | Supervision strength | X1 |
| | Relevant laws and regulations | X2 |
| | Investment intensity | X3 |
| | Guiding direction and decision | X4 |
| School main body | Hard strength of running school | X5 |
| | The rationality of course content | X6 |
| | The perfection of running school theory | X7 |
| | Teacher comprehensive ability | X8 |
| Industry subject | Industry hard power | X9 |
| | The improvement of the industry internal links | X10 |
| | Industry development sustainability | X11 |
| | Industry development purposes | X12 |

set as 10 points. The scores of the indicators are obtained by a questionnaire. Then a factor analysis model is constructed to analyze the influence degree of all indexes. The relevant model construction formula is shown as follows:

$$X = AF + \varepsilon \tag{1}$$

$$X = [X1,\ X2, \cdots, Xp] \tag{2}$$

$$F = [F1,\ F2, \cdots, Fm] \tag{3}$$

$$A = \begin{bmatrix} a11 & a12 & \cdots & a1m \\ a21 & a22 & \cdots & a2m \\ \vdots & \vdots & \vdots & \vdots \\ ap1 & ap2 & \cdots & apm \end{bmatrix} \tag{4}$$

## 4. RESULTS ANALYSIS AND DISCUSSION

### 4.1. Screening of primary indicators

SPSS22.0 software was used to conduct the Pearson correlation screening of all primary indicators. The results showed that 5 indicators, namely X2, X5, X6, X11 and X12, might have a possibility to confuse with other indicators. Therefore a total of 7 indexes were selected, namely X1, X3, X4, X7, X8, X9 and X10, Table 2.

### 4.2. Correlation analysis of influencing factors through factor analysis model

According to the survey conducted among different groups of people, all indicators were scored after the Pearson correlation analysis, and the factor analysis model was used to analyze the influence of all indicators on the operation mode of PV and SL enterprises participating in VE. The analysis results are shown in Table 3. Among them, the most influential factor was the degree of improvement within the industry.

### 4.3. Suggestions and strategies for the operational mode of PV and SL enterprises participating in VE in China

This work analyzed and explored main influencing factors of the operation mode of China's PV and SL enterprises participating in VE according to the factor analysis model so as to find the deficiencies in enterprises operation mode. In view of identified deficiencies, the author proposed some suggestions in an attempt to provide a theoretical basis for improving the operation mode, Fig. 3.

## 5. CONCLUSION

At present, it is a necessary demand of rapid economic development to utilize massive energy amounts and resources, but huge consump-

**Table 2. Pearson analysis of primary indicators**

| Index parameter | X1 | X3 | X4 | X7 | X8 | X9 | X10 |
|---|---|---|---|---|---|---|---|
| X1 | 1 | | | | | | |
| X3 | 0.482 | 1 | | | | | |
| X4 | 0.414 | 0.479 | 1 | | | | |
| X7 | 0.388 | -0.431 | -0.556 | 1 | | | |
| X8 | 0.423 | 0.475 | 0.578 | 0.779 | 1 | | |
| X9 | -0.717 | -0.707 | 0.641 | -0.502 | 0.415 | 1 | |
| X10 | -0.694 | 0.677 | -0.756 | -0.440 | 0.285 | 0.345 | 1 |

**Table 3. Correlation analysis of influencing factors through factor analysis model**

| Index parameter | Correlation degree | Sorting |
|---|---|---|
| X1 | 0.445 | 6 |
| X3 | 0.499 | 4 |
| X4 | 0.623 | 2 |
| X7 | 0.582 | 3 |
| X8 | 0.423 | 7 |
| X9 | 0.498 | 5 |
| X10 | 0.633 | 1 |

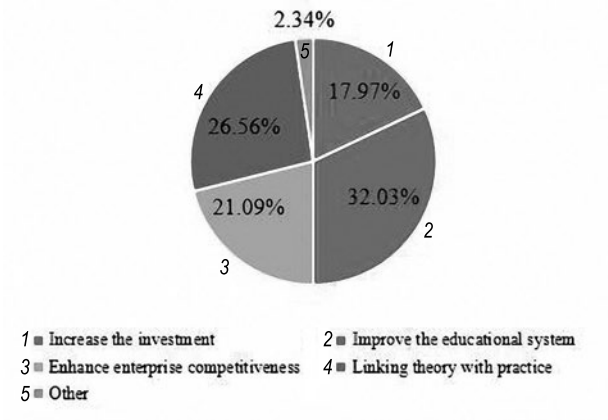


Fig. 3. Suggestions and strategies for the operational mode of PV and SL enterprises participating in VE in China

tion of traditional resources leads to a depletion of resources and energies and poses threat to China's environment and ecology. Against such background, China's new energy enterprises begin to appear and develop, and it requires China's VE to cultivate more professional talents. However, there are some deficiencies in China's VE. In view of this uncoordinated phenomenon, after analysis and generalization of relevant data, this work summarized main influencing factors of VE operation mode based on the factor analysis model and provided some suggestions for the operation mode of China's VE. The work aims to provide a theoretical basis for the development of China's new energy enterprises and some scientific basis for the development of China's VE operation mode.

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# CROSS-CULTURAL EDUCATION SYSTEM IN PHOTOVOLTAIC ENTERPRISE EMPLOYEES ENGLISH TRAINING

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**ABSTRACT**

The narrow domestic market cannot satisfy photovoltaic industry's massive output, so expanding this market and opening up the international market are urgent tasks. In international environment it's necessary to strengthen employees' English training and improve their cross-cultural communication abilities. This paper reviews a huge amount of domestic and foreign literature. In line with current situations at domestic photovoltaic enterprises, this paper describes questionnaire surveys of some enterprises' training, including pre-training investigation, after training effect check, and before-and-after oral English comparison. The collected data were analyzed by SPSS software. Results show that professional English training is of great necessity, and oral English is a prevailing weakness. Employees' overall abilities are greatly improved after professional English training which is of great significance for photovoltaic enterprises better adapting to international market and for cultivating international talents with professional knowledge and good English communication skills.

**Keywords:** photovoltaic enterprise, training in English, cross-cultural education

## 1. INTRODUCTION

With economic globalization and the coming knowledge economy era, Chinese enterprises' going out is faced with opportunities and challenges. Going out can facilitate Chinese enterprises by opening the international market and expanding their business overseas, so it plays an important role in promoting their development [1]. As a representative of new energy industries, domestic photovoltaic (PV) companies are rapidly developing and expanding, and their output accounts for one third of the world total. However, there are some urgent problems to be solved such as lack of a core technology, narrow domestic market and imbalance between its output and market demands. Therefore, expanding the market and opening up international market are urgent tasks for PV industry [2].

Opening up international market requires professionally skilled managers and well-rounded staffs with professional skills and good English communication skills. Although some enterprises have been aware of this problem, most of them haven't realized the importance of cross-cultural English training for employees. Therefore, there are many professional and experienced old staffs with poor English ability, or college graduates with English communication skills but lacking professional skills. Those graduates, however, have only mastered everyday life English but little professional English of their trade [3]. In China the common problem is lacking English speaking and communicating environment, so employees' English speaking abilities are extremely poor. Therefore, in most PV enterprises there are cross-cultural communication difficulties.

## 2. STATE OF THE ART

Cotelli et al. found that a dozen Japanese multinational companies have invested a lot of money and energy in human resource management. In ad-

dition to employees' professional training, they also provide employees with specialized English training which can help them to adapt to overseas work [4]. Hagedoorn J. & Cloodt M. found that Malaysia has established a special English development group to provide professional English training for professionals and technical staffs, so they can communicate with foreign employees without obstacles, and it can also facilitate them carrying out overseas work [5]. In his research Antoniou found that many companies in South Korea have sent their employees to English speaking countries for specialized language training. Technical personnel with better English are more likely to get better job opportunities with higher salary and better development than those who are not good at English communication [6]. Ji X. & Li H.B. found that English training for employees has a positive impact on the development of individuals and enterprises. Strengthening the training in English language can not only improve individual's learning and work abilities, but can also provide more spaces and better opportunities for their development. For enterprises, professional English training can make ordinary technical staffs become elites of the industry and eventually become international well-rounded talents [7].

Investigation of a number of PV companies has shown that many companies have set up English training systems [9]. However, these systems still have many problems. Firstly, at many PV enterprises, due to the lack of their own professional English trainers, employee training is mainly done by teachers from language training institutions. Those teachers, however, are good at social language training, but do not have the professional knowledge of PV enterprises, so training effect is not very satisfying [10]. Secondly, the training requirements are not clear, and the training management is poor. The training process lacks strict management and the training is superficial, with a result of many employees' deliberate absence. At the same time, many training institutions lack professional English training ability, and they pay too much attention to professional vocabulary and dialogue training, but ignore Basic English. After attending these two kinds of training, employees still cannot speak and use English, because these trainings are just processes that can never achieve effective results [11]. Thirdly, trainers' abilities are not up to standard. Most English training institutions in China are profitable institutions, which usually

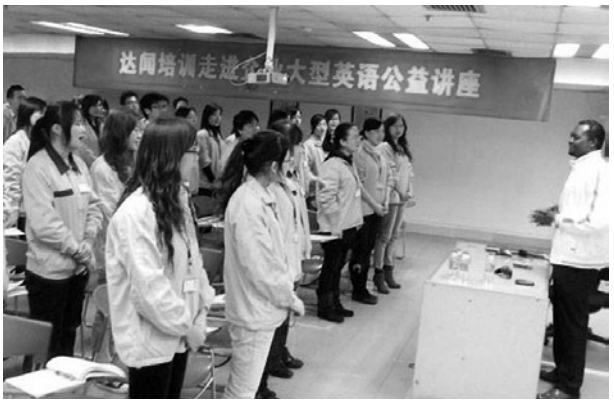


Fig. 1. English training for employees at a PV enterprise

use the same set of training courses for all enterprises, so they are unable to carry out specialized training for specific industries. Moreover, the contents of this kind of training classes are extremely boring, so it is difficult to arouse trainees' interest [12]. Fourthly, there is no standardized testing and evaluation in the training, so the training can't really achieve the desired effect [13].

This paper reviews a huge amount of domestic and foreign literature. In line with current situations at domestic PV enterprises, this paper describes questionnaire surveys of some enterprises' training, including pre-training investigation, after training effect check, and before-and-after oral English comparison. The collected data were analyzed by SPSS software. Results show that professional English training is of great necessity, and oral English is a prevailing weakness. Employees' overall abilities are significantly improved after professional English training which is of great significance for PV enterprises better adapting to international market and for cultivating international talents with professional knowledge and good English communication skills, Fig. 1.

## 3. METHODOLOGY

Three methods were used in this study: a literature review, a questionnaire survey and a comparison of test results before and after the training.

### 3.1. Literature review

In this study a large number of Chinese and foreign publications were studied. Through the literature, current situation in a cross-cultural education system at Chinese and foreign enterprises was analyzed, and problems in the training process were

**Table 1. The questions of a demand survey for technical staff English training at PV enterprises**

| Problem dimension | Survey content |
|---|---|
| Essential information | Age, education, working years, English class, etc. |
| Target demand Problem dimension | Knowledge needed |
| | Current lack of knowledge |
| | Yearning for knowledge |
| Essential information | English learning attitude |
| | English learning habits |
| | Views on the training environment (natural and human) |

**Table 2. The questions of a satisfaction feedback survey for technical staff of PV enterprises**

| Problem dimension | Survey content |
|---|---|
| Course content feedback | Curriculum objectives, the overall framework, practicality |
| Teaching organization feedback | Teaching environment, auxiliary tools, learning atmosphere |
| Training teacher feedback | Professional level, lesson preparation, teaching methods |
| Training effect feedback | The degree of help, expectations realization |

summarized. Methods that can effectively solve these problems were summarized to provide an effective theoretical basis for this study.

### 3.2. Questionnaire

In this study, 149 PV enterprises employees were surveyed by two questionnaires. Before training, a questionnaire on training needs was conducted on 149 employees. After training, a feedback survey of training satisfaction was carried out on the same 149 employees. The contents of the questionnaires are shown in Tables 1 and 2.

### 3.3. Test survey

In this study the oral proficiency of employees participating in the training was tested. Before and after the training professional trainers set up various professional technical questions in the area of PV industry. In the process of testing, there were special staffs to record and maintain performances of employees for comparison before and after the test. The judges were 3 professional trainers, and the final result was the average score.

## 4. RESULTS ANALYSIS AND DISCUSSION

### 4.1. Analysis of the demand for engineers' and technicians' English training at PV enterprises

Two questionnaires were conducted on 149 PV companies' employees. Among these 149 employees, the ratio of male to female was 3 to 2, and most people have a bachelor's degree or above, so they have Basic English knowledge. However, after graduating from college, in the course of their work, they seldom use English, so their Basic English skills have lowered. Before training, a questionnaire on training needs was carried out on 149 employees. After training, a feedback survey of training satisfaction was carried out on them again. The data of two questionnaires were tested by SPSS, and results are presented in Table 3.

From the above data, it can be seen that the reliability coefficients of the two questionnaires were above 0.7 which means the data has high reliability, so it can be used for investigation and analysis, and it can scientifically explain the problem.

Through the investigation and research on the English requirements before training, it was found that among 149 employees participating in this survey only 5 people had no plans to go abroad, and the remaining 144 employees had a short-term or long-term plan or the possibility of foreign work. Therefore, it shows that in the PV companies the possibility of technical staffs to work abroad is relatively higher, and they have higher demands for the English training.

### 4.2. Analysis of the effect of PV enterprises technical personnel training

The employee's spoken English level was chosen as an indicator of the effectiveness of the English language training. Three professional trainers rated the test, and the average score was chosen as

**Table 3. Test results of the reliability of the questionnaire before and after the training of the technical staffs in the PV industry**

| Questionnaire | Dimension | Each dimension Cronbach's Alpha | Total Cronbach's Alpha | Number of items |
|---|---|---|---|---|
| Training needs survey | Target requirement analysis | 0.775 | 0.851 | 22 |
| | Learning needs analysis | 0.845 | | |
| Questionnaire | Course content | 0.857 | 0.939 | 20 |
| | Teaching organization | 0.819 | | |
| | Training teachers | 0.920 | | |
| | Training effect | 0.864 | | |

**Table 4. Statistics of average scores of PV enterprises technical staff**

| Test | Fluency | Vocabulary | Grammar | Pronunciation and intonation | Final score |
|---|---|---|---|---|---|
| Before the training | 3.72 | 3.57 | 3.71 | 3.96 | 3.75 |
| After the training | 5.41 | 5.35 | 5.01 | 5.00 | 5.20 |

the final performance of the staff. The main judging standards were language fluency, the use of professional vocabulary, grammatical errors, as well as pronunciation and intonation. In the test, the highest score is 9 and the lowest score is 1. Table 4 shows the average score of trainees in above several aspects before and after the training.

The level of oral English before and after the training was analyzed by SPSS software. It was found that the average value of oral assessment was 3.75 before training, and the standard deviation was about 1.132. Before the training, their scores are mainly between 2 and 5, and the skewness is 0.021, and it means that the number of people above and below the average is basically the same, but the range reaches 5.4. Therefore, we can see staffs' English level was polarized, because some employees had good Basic English, while some employees' level was extremely low. The highest score is 9 while the average is 3.75 which reveal staffs' generally weak basic knowledge and low level of spoken English. Most employees basically can understand English, but they found out that speaking English is extremely difficult and that they couldn't express themselves in fluent English. In terms of 4 judgment aspects, the vocabulary had the lowest score, indicating that staffs were not familiar with professional vocabularies. The language fluency got only 3.72 points, which means that staffs can understand the basic meaning of the questioner, but they are unable to organize their own language and to express their ideas in a coherent way. Moreover, in the process of expression, there were improper usage of words and some grammatical errors. After the training, English speaking score's skewness was close to zero, and the overall score showed an obviously normal distribution. The average score of oral English was 5.20 where staffs' main scores are between 4 and 6 which was significantly higher than before training. Among them, the average score of fluency was 5.41, the highest score in the evaluation of the four items. Vocabulary score also rose to 5.35, indicating that after the English training, employees have had a significant increase in professional vocabulary, and their language is relatively smooth now. Although their pronunciation is not standard, they have been able to communicate with each other by using appropriate sentences.

### 4.3. Results of English training satisfaction feedback of PV enterprises technical staffs

After training, in order to better understand the effect of training and employees' satisfaction, the

**Table 5. Results of English training satisfaction feedback of PV enterprises technical staff**

| Project | Very dissatisfied (%) | Not satisfied (%) | General (%) | Satisfactory (%) | Very satisfied (%) |
|---|---|---|---|---|---|
| Course objective | 1.6 | 3.2 | 16.0 | 28.0 | 51.2 |
| Time arrangement | 0.0 | 8.8 | 32.0 | 36.0 | 23.2 |
| Teaching environment | 0.8 | 4.0 | 32.0 | 45.6 | 17.6 |
| Teachers' professional knowledge | 0.8 | 1.6 | 24.8 | 36.8 | 36.0 |
| Teaching method | 1.6 | 2.4 | 12.0 | 47.2 | 36.8 |
| Teaching skills | 0.8 | 2.4 | 10.4 | 45.6 | 40.8 |
| Original expectation | 2.4 | 4.8 | 20.0 | 48.0 | 24.8 |
| Bring help | 0.0 | 3.2 | 4.8 | 32.8 | 59.2 |
| Comparison of effect and expectation | 0.0 | 4.0 | 10.4 | 48.8 | 36.8 |
| Comprehensive evaluation | 0.0 | 8.0 | 36.8 | 40.8 | 14.4 |
| Willingness to participate | 0.0 | 3.2 | 21.6 | 47.2 | 28.0 |

satisfaction of staffs who participated in the training was investigated. Feedback results are shown in Table 5.

As can be seen from the above data, among PV technology staffs who participated in the investigation, only about 9 % of people were not satisfied with the overall effect of English training, while the remaining 91 % of employees were satisfied. Before the training, most of PV companies technical staffs had high expectations for this English training. More than 90 % of staffs believe that this training brought some benefits to them. According to the analysis, the reason for a small number of staffs' low expectations or low satisfaction was that they had poor English basics, so they learnt English with low self-esteem, or they were not interested in this training. As for the reason behind some staffs' non-satisfaction with the training, they feel that the training lacks individualized approach to staffs' specific weaknesses with a result of poor knowledge and unsatisfied application in reality. However, most of the trainees achieved satisfactory results through this training. Among them, 76.2 % of staffs had the willingness to participate in training again. In addition, a feedback survey was carried out concerning four aspects, that is course contents, teachers' abilities, the teaching mode and the training effect, and results are shown in Fig. 2. Overall, English training can have satisfying training effect, and it plays a positive role in promoting the development of technical staffs and the expansion of enterprise market. Through analysing the data, we can see most employees have some English basics, but their English knowledge was gained before their graduation, so it is more of daily English than professional English. After the professional English training, however, employees can get significant improvement within a short time.

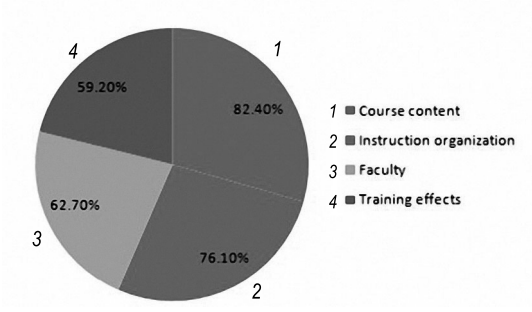


Fig. 2. PV enterprises technical staffs' satisfaction with English training

## 5. CONCLUSION

China's PV enterprises are plagued with productive but narrow domestic market. Therefore, Chinese enterprises' going out has opportunities and

challenges. Going out can facilitate for Chinese enterprises the opening of international market and expanding their overseas business which will play an important role in promoting their development. This paper has conducted questionnaire surveys of some enterprises' training, including pre-training investigation, after training effect check and before-and-after oral English comparison. The collected data were then analyzed by SPSS software. Results show that most employees had mastered some Basic English in their college education. Employees on technical posts are less exposed to English, so they have forgotten much of their English knowledge. Besides, employees have small terminology vocabulary, which makes it more difficult for actual application. Therefore, professional English training for employees is extremely necessary for the industry, and English speaking is a prevailing weakness. Employees' overall abilities were much better after professional English training, and the comprehensive level of employees was significantly improved, which is of great significance for the PV enterprise better adapting to the international market, and for cultivating international talents with both professional knowledge and good English communication skills.

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# INCENTIVE MECHANISM FOR CORE TALENTS OF SOLAR PHOTOVOLTAIC ENTERPRISES

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**ABSTRACT**

The booming science and technology has greatly shortened upgrade cycles of products, so how to attract and retain core talents has become the key to sustainable development of modern enterprises, especially high-tech enterprises. In order to retain core talents, mobilize their enthusiasm and tap their potential, enterprises should establish a set of scientific incentive mechanisms with corresponding strategies. This paper, firstly, expounds the concept and content of core talents, analyses score talents characteristics and determines the composition of core talents in a photovoltaic technology company. Secondly, a comprehensive analysis of domestic and foreign relevant incentive theories was reviewed and summarized. Thirdly, photovoltaic technology company's current core human resource management situation was thoroughly analysed, and existing problems in core talent incentives were summarized. Finally, on the basis of the above, solutions were put forward to solve problems in photovoltaic technology enterprises' core talent incentives.

**Keywords:** motivation, core talents, photovoltaic technology company

## 1. INTRODUCTION

Economics defines resources, as everything that can be used to create material wealth for mankind, which include not only natural resources such as mineral deposits and trees, but also social resources, such as scientific and technological achievements, invention patents, human resources, etc. [1]. In the new era of knowledge economy, human resources, as the most important resource for enterprises' survival and development, have been recognized. The competition of modern enterprises has been shifted from capital, scale and cost competition to talents, especially core talents, competition [2]. Nowadays, in order to gain advantages in fierce market competitions, high-tech enterprises must focus on core talents management. The key to retain core talents, mobilize their enthusiasm and tap their potential is to establish a set of scientific incentive mechanisms with corresponding incentive strategies [3]. For enterprises, positive and effective incentive strategies, as an important part of enterprise management, can stimulate core staff's motivation, and further promote the establishment of company's core system. Only when incentive methods are reasonable and effective, and incentive strategies are used as a guide for core employees' continuous progress, reasonable incentive systems can have theoretical basis and guarantee [4]. Cultural management, which can cultivate a sense of value and belonging, is a central factor in modern enterprise management. Based on people's psychological and behavioural characteristics, cultural management can be individualized in different corporates. Then, corporate culture can encourage core staff's enthusiasm and transform it into practice. Generally speaking, cultural management is people-oriented where people are central and enterprises achieve development through enterprise spirit and culture [5].

## 2. STATE OF THE ART

### 2.1. Foreign research review

Chinese and foreign scholars have done a lot of research on core talents motivation, and have achieved practical results.

Core employees want their job to satisfy their interests with desirable salaries. In fact, however, it is not remuneration and job promotion, but the nature of the job and the feeling people get that is the best incentive. Work itself is the most satisfying reward for employees. The principle for core employee motivation includes following aspects: promising and challenging work, interest realization in the work, recognition of employee's work style and available training opportunities [6]. Core employees can be divided into four categories: unique talents, deputy personnel directors, general talents and core talents. Those four core employees play different roles in companies. The work of the core talents, however, can't be replaced at will. The value they create far exceeds the cost of hiring them. Therefore, their employment is special. To reduce core staff turnover, or to make appropriate incentives, enterprises should design some incentive strategies, such as training core staffs, so that they can improve their skills and overall quality. Starting from managers, they can manage in a more humane way, so that core employees feel free to carry out the work, and enjoy fruits of company development [7]. American scholars have designed four strategies. The first is to make the company a place where people are willing to work. The second is to wisely select talents. The third is to let employees have a good start. The last is to encourage core staffs' loyalty, so as to reduce their mobility. At the same time, in stimulating core employees, managers should learn from successful practices and experiences. And enterprises should regulate their own actual situation, so as to develop and form a unique incentive system [8].

To sum up, most foreign scholars have analysed the incentive mechanism of core employees from a macro perspective. However, the number of researches on the effectiveness and practical problems of incentive mechanism is small. As for problems in core staff incentive, most scholars have paid attention to the incentive system, ignoring the analysis of its implementation. Moreover, analysis of and research on safeguard measures for incentive mechanism are also rare.

### 2.2. Chinese research review

The first Chinese paper on core employee motivation was published in 2001. Up to now, there are over 200 papers on this subject. At present, there are many researches on core staffs, while there is no systematic arrangement and analysis. Therefore, to satisfy research needs, this paper systematically arranges and studies Chinese researches on core talents. Based on the definition of core staffs, we can use weighted summation method based on the same standards to divide employees into two levels. Standards of the first level are to consider individual's physical qualities and skills. The second level is based on the enterprise's overall strategy and core competence: core staffs should be judged in accordance with hierarchy that is only when they meet standards of the first level can they be tested by standards of the second level [9]. Enterprises can take positive measures. Core staffs can be trained from the start of their recruitment; in training core employees, their recognition of enterprise culture should also be cultivated; core staffs can have opportunities to manage the enterprise; performance evaluation and compensation system should be fair and just. An enterprise's core resources are their core staffs that are the most critical part of the enterprise. In order to improve effective recruitment of core employees, companies should have their own planning and develop reasonable recruitment programs. Companies can call experienced employees to form recruitment teams, establish good corporate images and so on. In core talents incentive, the following points are important. Firstly, core employees' self-esteem is very important, and enterprises should respect them and provide them with a home-like atmosphere, which can facilitate their work. Secondly, core staffs should be given full trust. When encountering some problems, companies can delegate the power to core employees and let them handle problems independently. Thirdly, there should be frequent communication between business managers and core staffs. Fourthly, company's promotion system should be improved, so that core staffs can obtain more promotion opportunities. Fifthly, company should realize that career planning is very important, and

**Table 1 Characteristics of core talents**

| Features | Performance |
|---|---|
| High quality, strong ability to work | The core talents usually have high skills, specialized knowledge, the ability of continuous innovation and learning, high quality, strong ability to work. |
| Pursuing self-value realization | The core talents should pay more attention to the realization of self-value than to passive completion of general affairs, and strive for progress, surpass themselves, and dare to try and challenge new affairs. |
| Scarcity and low substitutability | The ability and skill of core talents need to be accumulated after a long time of study and practice. So a core talent is scarce. Low substitution refers to that most of them are engaged in top-paying jobs. The renewal of expertise and technical ability is difficult to copy, and the staff of the general affairs is difficult to match. |
| High efficiency | Core employees control core resources of the enterprise, and they can take advantage of skills, technology and resources to create a higher efficiency for the enterprise, etc. The characteristics of the core staff also make the core talent incentive management different from the general staff incentive management. |

they should think about core employees and develop suitable career planning for them [10].

Through comprehensive analysis, we find that Chinese and foreign scholars have analysed the management of core talents from theoretical or macro perspectives. Few researches consider the practical perspective and concentrate on specific company cases. Therefore, this paper analyses specific company' cases from a practical perspective.

## 3. METHODOLOGY

### 3.1. Core talents

Core talents generally have characteristics, shown in Table 1.

### 3.2. Incentive mechanism

Motivation is a basic psychological concept that refers to the interaction between individual's behaviours caused by people's needs and purposes of such behaviours [11]. In management, motivation is to mobilize individuals' initiatives and improve work efficiency. This mechanism can stimulate individuals in two aspects, internal and external, so as to achieve the best working condition.

Incentive mechanism refers to the use of a variety of different incentives to motivate subjects in an organizational system that can later become standardized and relatively fixed. It is a summation of interaction between subjects and objects. Incentive mechanism is a kind of means to make the virtual ideal into reality that contains material and spiritual incentives.

### 3.3. Basic tasks in constructing core talents incentive mechanisms

The purpose of developing core talents incentive strategies in a photovoltaic technology company is to stimulate core staffs' initiatives, embody spirits of the company, and take short-term material incentives and long-term cultural incentives into account. In addition, it is to meet the needs of core talents at all levels, so as to make personal goals consistent with the company's development goals, and to achieve company's sustainable development. Basic tasks in developing core talents incentive strategies are as follows. For one thing, in the case of limited resources, the company is expected to establish a core talents incentive policy to properly allocate the limited resources, so as to avoid waste and to improve efficiency. For another, photovoltaic technology company's work environment should be fairer and just, so that all core employees feel that they are treated fairly and can make better contributions to the company, which can facilitate building strong core talents teams.

### 3.4. The design of material incentive scheme for core talents in photovoltaic technology company

Annual salary system: the annual salary system is designed for company's top management person-

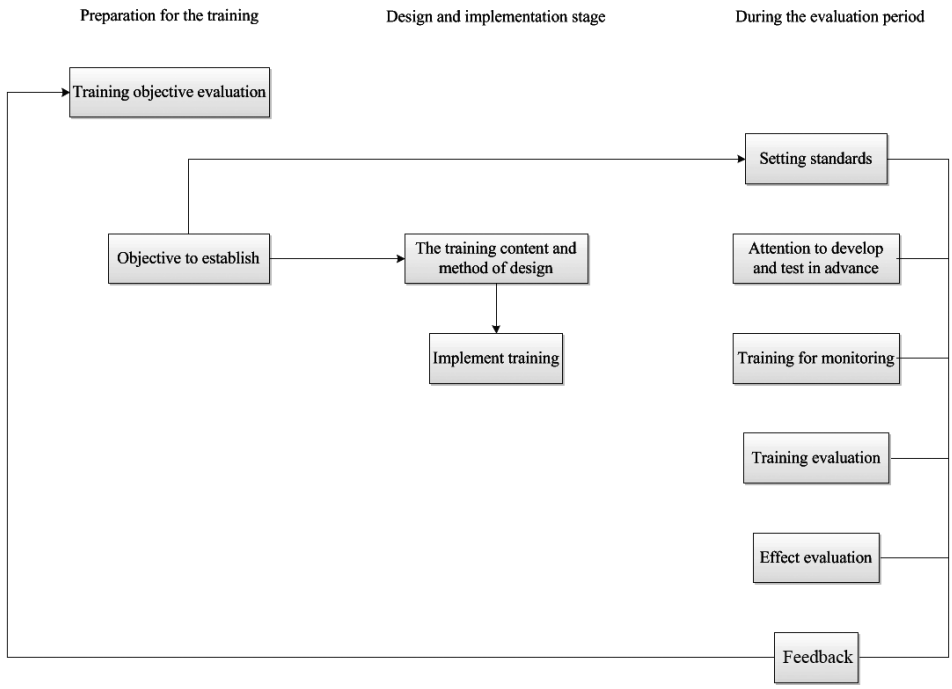


Fig. 1. Core staff training flow chart

nel, core talents and senior technicians. Annual salary system can improve their work initiatives and tie them with the company, so as to enhance their sense of responsibility. The annual salary consists of basic salary, performance salary and special honour allowance. Annual salary should assess not only the performance of core staffs, but also the overall performance of their departments, so as to enhance their team consciousness. The formula of annual salary can be written as:

$$\textit{Annual Salary} = \textit{basic salary x 13} + \\ + \textit{performance salary} + \textit{allowance} + \textit{various special honour allowance.} \quad (1)$$

The formula of performance salary can be written as:

$$\textit{Performance salary} = \textit{target performance salary x personal performance coefficient} \times \\ \times \textit{department performance coefficient} \times \\ \times \textit{company performance coefficient}. \quad (2)$$

Long service award scheme: long term service award is a program that encourages core employees to work in the company for a long time and maintains their working enthusiasm. Core staffs in the program can get a reward fund, and the formula can be written as:

$$\textit{The total reward fund} = \textit{basic monthly salaries of core staffs in this program} \times \\ \times \textit{36 months} \times \textit{15 \%}. \quad (3)$$

Incentive fund is based on increased basic salaries of core staffs after participating in the program, and any later award for their special contributions cannot be calculated in this.

Three years later, the company can offer a one-time bonus for core staffs that are still in service.

Internal experts' award scheme: internal expert is a title of honour, but also as recognition of high skills. The plan is to improve core staffs' overall qualities and skills.

### 3.5. The design of core talent training mechanism of a photovoltaic technology company

Companies carry out training to give technical support to core employees in need. In order to meet core employees' occupational demands and to further improve company's work efficiency, the training of core employees should be carried out effectively and efficiently. Fig. 1 shows the core staff training flow chart.

Before training core employees, it is important to know the purpose of training and what effects can be achieved through training. Training content should be decided according to company's actual

**Table 2. Comparison of results**

| % | Employee turnover rate | Performance growth rate | Technological innovation rate | Market share growth | Staff quality improvement rate |
|---|---|---|---|---|---|
| Before experiment | 16.4 | 10.3 | 5.6 | 3.2 | 5.6 |
| After experiment | 3.4 | 20.5 | 12.6 | 9.5 | 11.5 |

situation and core staff's personal skills. Moreover, core staffs' needs should be found out, and a variety of training programs can be developed and executed targeting these different points.

After completing the training plan, we will move on to the implementation. In actual implementation, the human resources department should carry out classified training of core staffs in different positions and with different needs. Enterprises can carry out open courses, professional courses, or invite experts to give lectures for core staffs. Open courses cover a broad range, which is more suitable for managers. For professional core technical talents, open courses and expert explanation are more suitable, from which they can learn more skills. The evaluation of training effect is to check training quality, based on which, the enterprise can make analysis and conclusion, or share successful experience and then find out shortages and problems serving as references for future trainings.

## 4. RESULT ANALYSIS AND DISCUSSION

A photovoltaic enterprise was selected to apply the core talent incentive mechanism established in this paper. Results of this study were verified by a concrete example. Through a period of 3 years of experiment, and compared with data before the experiment, following results were obtained, as shown in Table 2 and Fig. 2.

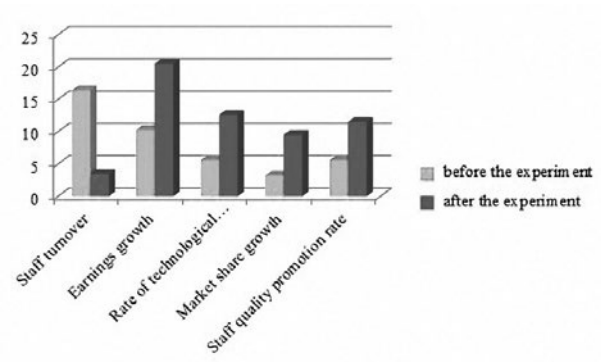


Fig. 2. Comparison of results

From the above charts, it can be found that staff turnover rate has dropped to a large extent after the application of the core talent incentive mechanism, showing that a good incentive mechanism can help employees to establish a better sense of belonging to the enterprise, and also can help enterprises attract more talent. In addition, after the experiment, the enterprise's performance, its technology innovation, product market share, staff quality and other aspects have been greatly improved. This fully shows that a good incentive mechanism can help enterprises to establish better market competitiveness and create better performance, and as a result it will help enterprises to develop and grow further.

## 5. CONCLUSIONS

With the booming science and technology industry, photovoltaic technology companies are facing challenges of how to improve current core talent incentive model to break through their development bottlenecks. In line with the three-step method, that is asking questions, analysing problems and solving problems, this paper firstly expounds concept and content of core talents, analyses characteristics of core talents and determines the composition of core talents in photovoltaic technology company. Secondly, a comprehensive analysis of domestic and foreign relevant incentive theories was reviewed and summarized. Through the comparative analysis of domestic and foreign incentive ideas and viewpoints, the role of incentive theory in establishing a reasonable incentive strategy for photovoltaic technology company was pointed out. In addition, photovoltaic technology company's current core human resource management situation was thoroughly analysed, and existing problems in core talent incentives were summarized. On this basis, photovoltaic technology company's

core talent incentive strategy was developed. At the same time, in order to ensure actual implementation, relevant supporting measures were also put forward in this paper.

This paper has some limitations. Although motivation has been discussed in depth, the core staff welfare issues are not covered. Moreover, there is no model for incentive mechanism, which should be further explored. In addition, there may be some problems in determining core talent incentives, which will complicate the assessment work. Therefore, human resources departments' effectiveness should be reviewed in an actual implementation. Moreover, there are still a lot of constraints in the input and output of core talent incentive measures. And so, recognition and investment from the management, as well as support from human resources departments are indispensable.

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# RESEARCH ON THE MODE OF VOCATIONAL EDUCATION FOR PHOTOVOLTAIC ENTERPRISES

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**ABSTRACT**

In recent years the photovoltaic (PV) industry has become one of China new industries with a soaring-up demand. Therefore there is an urgent need for research on vocational education modes for training PV enterprise employees. This paper analyses the necessity to innovate the vocational education mode of PV enterprises in China and expounds the explorations for the new ones. By analysing the three types of vocational education this paper concludes that the education mode based on a modern information technology and platform is more extensively applied in PV enterprises since it can cultivate more talents in line with the enterprise demand as well as reduce the cost.

**Keywords:** photovoltaic, enterprise employees, vocational education mode

## 1. INTRODUCTION

With the continuous development of science and technology, PV industry has developed rapidly in recent years in China and became one of its emerging industries. With constant improvement of China economy, the technical requirements for PV industry in China will be higher and higher. Therefore there will be an increasing demand for highly skilled technical personnel. Some scholars point out that the PV industry is a technology-intensive industry, which needs a large number of technical personnel, and with the continuous development of technology the demand for the quality of PV enterprises professional staff will be even higher [1]. At the same time, a survey shows that PV industry, both in China and abroad, is facing an acute shortage of senior technicians both in production management and in research and development especially of highly skilled technicians [2]. Some scholars believe that in this case PV enterprises should focus on training senior personnel to improve the overall professional quality of their employees, and the vocational education (VE) is one of the most effective ways to do it [3]. However, the traditional mode of VE in today's ever-changing market has been unable to meet the needs of PV enterprises while the VE at the enterprises alone is not sufficient to support the continued development of them [4]. Therefore, some scholars believed that PV enterprises have to be innovated in their education modes to meet the needs of the enterprises and society for their employees' qualification [5]. And thus, the mode of VE for PV enterprise becomes a hot topic of research.

Based on the current research status and achievements of the VE at PV enterprises, this paper first reviews the research on the VE model in PV enterprise and its relevant theories. Then the author elaborates the development and current state of the VE at home and abroad and the problems that exist in the traditional vocational education. In the third part the author analyses the necessity to innovate the VE of PV enterprises in our country and expounds the exploration for the new mode of VE at PV enterprises. Then the collected data is analyzed by TOPSIS method. Finally the author summarizes the results of this study of VE mode for PV enterprise employees training.

## 2. RESEARCH REVIEW

### 2.1. The development and research status of VE research in China and abroad

In developed countries the research on VE started a little earlier than in China. Eric Fries Guggenheim in his "platform theory" put forward the German «dual vocational system». In this model there is usually a big gap between the productive value of the apprentice who is engaged in training and the expected value of employers who are offered training opportunities, so the companies are generally reluctant to offer more internship opportunities to apprentices [6]. However, the apprentices under training can master the learning content by being involved in the actual or simulated production practices. Therefore, the establishment of a platform where apprentices can participate in the practice is very important. In the VE the actual needs of the firm are important factors in determining the direction of the individual's VE [7]. Since whether employees need to take part in higher VE or not is determined by their work responsibility and achievements, apprentices should actively accumulate their personal experience and strengthen their interdependencies with enterprises so that enterprises can attach more importance to the technical training of apprentices [8]. In 2005 Thomas Sondermann put forward in one of his articles that the prerequisite for enterprises to participate in VE was to achieve the coordination between departments and VE. In the course of VE, the personnel was trained directly in the working process, so the training activities and the organization of professional activities had a certain relationship [9]. Therefore the implementation of learning tasks should be carried out in different areas of practice. As different training sites will assign different tasks to their apprentices, the evaluation is usually based on how they perform the tasks and on the proficiency of their skills in performing these tasks [10]. In short, the training program can be organized and implemented only by cooperating with the technical department. In 2006 at the ASEM conference on VE and training Dr. Dipovsky from Germany, in one of the dialogues on "How to fully enhance the attractiveness of vocational education", talked about "the role and contribution of the private sector in the vocational education", and pointed out that "the public sector needs to provide certain prerequisites to encourage enterprises to invest in vocational education". The participants also discussed other issues of VE and training promotion [11].

### 2.2. The problems that existed in the traditional VE at Chinese enterprises

In China, the traditional VE is mainly carried out at the enterprises or in cooperation with universities. These two models have trained a large number of technical talents at the initial development stage of the PV enterprises. However, with continuous development and changes of the market, the PV enterprises demand for talents is also changing. The problem of traditional VE becomes increasingly prominent [12]. First of all, at present China doesn't have a complete training system for technical personnel with some scholars believing that the VE at the enterprises is sufficient to meet the needs of enterprises for their employees, while other believe that a more systematic training provided by colleges and universities is a better choice [13]. Nevertheless, either of them is facing the lack of resources, high cost and other problems of VE, and can't integrate the theoretical knowledge of the employees with practice and improve their operation ability in a short time. In addition some enterprises aren't paying enough attention to the employee's VE, and some even neglect the necessity of doing so blindly looking for profit. Consequently, they fail to pro-

Fig. 1. Current methods of PV enterprises VE

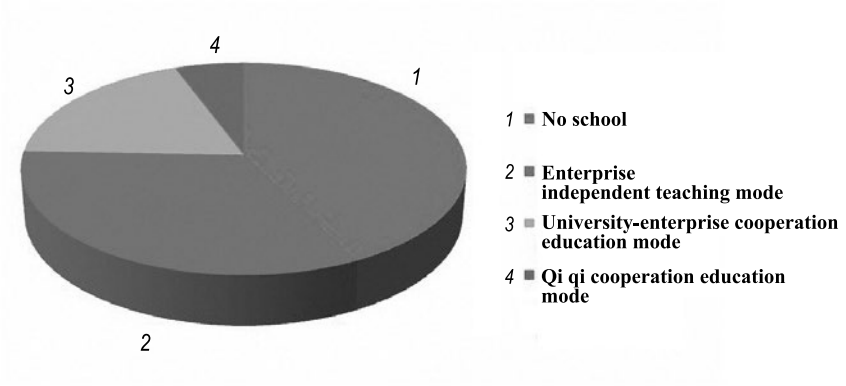


Fig. 2. The amount of PV enterprises employees who received VE in a certain areas

vide a good environment for their employees' development [14]. Fig. 1 shows current methods of PV enterprises VE.

## 3. METHODOLOGY

### 3.1. The necessity of the VE mode for Chinese PV enterprises innovation

With the rapid development of PV enterprises, the demand for high-skilled talent such as the talents in PV power generation is also growing. The traditional VE is facing great challenges. The traditional VE, which takes the in-service training within the enterprise as the mainstream and the cooperative education involving schools and enterprises and different enterprises as its supplement, is witnessing ever-increasing problems with the advancement of the technology although some good outcomes had been achieved in the past [15]. Fig. 2 shows the amount of PV enterprises employees who received VE in a certain areas. As can be seen from the figure, 42.5 % of the enterprises don't have their own training schools, while only about 33.1 % of them train their employees independently. The enterprises that have school-enterprise cooperation account for only 18.7 %, and those that provide education in cooperation with other enterprises account only for 5.7 %. This indirectly shows that PV companies in this region don't pay enough attention to VE, with few opportunities given to their employees for future promotion. What's more, the in-service training provided by the enterprises is relatively simple and is not sufficient to support the education of employees. And the cooperation possibility among enterprises in training their employees is also small due to the rights and liabilities problems.

Fig. 3 shows the degree of PV enterprises employees' satisfaction with their vocational education. As can be seen from the data, more than a half of employees aren't satisfied with the VE they received, and some employees even say that PV companies don't provide any training. Only 11.2 % of employees think that VE at PV enterprises can meet their needs, and it evidently indicates that the traditional VE at PV enterprises can't meet the educational needs of their staff. In addition, the survey shows that PV enterprises suffer a relatively high rate of talent loss; therefore many enterprises show no enthusiasm in the VE of their employees. And because of the various external conditions, there are serious deficiencies in school-enterprise cooperation VE and enterprise cooperation VE. The traditional VE cannot meet the demand for PV talents and therefore needs to be innovated.

### 3.2. Exploration on the new mode of VE at PV enterprises

The purpose of VE at PV enterprises is to improve the overall qualification of their employees and to cultivate more top talents to meet the needs of PV enterprises. Therefore a new VE mode should be developed for this purpose so as to meet the needs of PV enterprises employees training while developing the enterprises themselves. There are three new types of vocational education:

The first VE mode is the enterprise cooperative education based on modern information technology and platform. With the continuous improvement of China's economy, the market competition among enterprises is very fierce, and with the continuous development of the global economy many enterprises in China find it difficult for them to face the in-

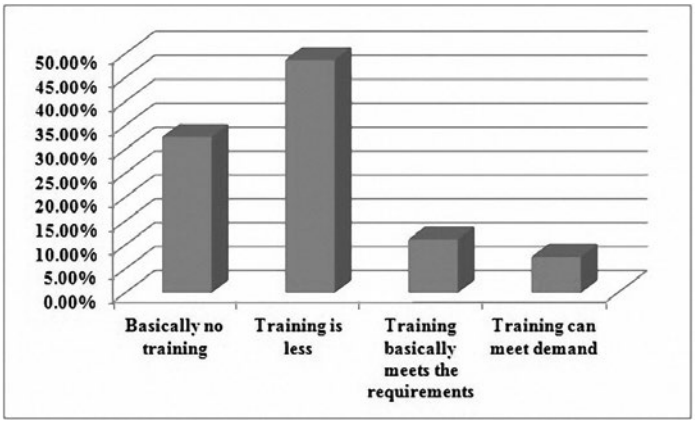


Fig. 3. The degree of PV enterprises employees satisfaction with VE they received at their enterprises

ternationalization trend and scale of the global market independently. The traditional VE is no longer able to meet the needs of PV enterprises for development and for talent. Therefore the cooperative education involving different enterprises comes into being. This kind of VE can make enterprises to complement each other, to reduce their personnel training costs and to improve their efficiency, and it can overcome the deficiencies of traditional VE, such as the absence of clear-cut demarcation between duties and responsibilities, paying attention only to the interests of one's own enterprise and ignoring the interests of their partners. The cooperative education based on modern information technology and platform can effectively solve these problems by sharing the educational resources among enterprises according to the training platform and negotiating and formulating the appropriate education rules for their platform. Therefore, it can greatly reduce the problems caused by trust and interest among enterprises.

The second one is the cooperative VE involving enterprises, colleges and universities. In the process of economy marketization and developing of enterprises, the government has been in a very important position to guide the enterprise to develop better. Therefore, in this mode of VE, the government is not only the maker and supervisor of the VE rules, but also will safeguard the interests of universities and enterprises and assess the achievements of VE. The government can also provide subsidies for enterprises and universities through educational funds. In this mode the colleges and universities should not only to establish a comprehensive system to carry out the VE, but also to develop the professional skills of their students according to the needs of enterprises and the actual requirements of the market. In this education mode enterprises maintain a dominant position, and they need to establish a sound relationship with colleges and universities and to cooperate with them by providing internships for students in order to improve their professional abilities as soon as possible.

The third mode is the engineering- centre-based VE. The engineering centre is the key point in this education mode, which not only works in a close cooperation with local PV enterprises, but also cooperates with universities in sharing their resources and professional abilities. The engineering centre can help employees to understand the core competitiveness of PV enterprises by providing them corresponding curriculums to improve their theoretical knowledge and operation ability. At the same time, the engineering centre can also provide internship for college students and enterprise employees so that they can improve their professional skills by putting their theoretical knowledge into practice.

In order to better understand and compare the three modes of PV enterprises VE mode, the author chose the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) to analyse them. The TOPSIS method is commonly used for the analysis of a limited number of multi-objective decisions in the project, and its basic principle is to find the best solution and the worst solution in the limited scheme based on the normalized original data matrix represented by the optimal vector and the worst vector. The decision makers endeavouring to avoid the most extreme situations can constitute a space in which the project to be evaluated is a point, and calculate the chosen alternative according to its geometric distance from the best solution and the worst solution in this space. It can

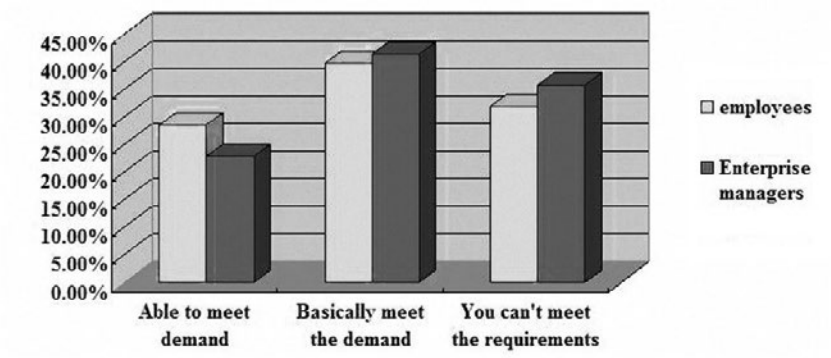


Fig. 4. What employees and managers of multinational corporations think about the VE based on a modern information technology and platform

be used as an evaluation standard. The basic steps are as follows:

– First of all, establish the decision matrix. This paper will evaluate 5 factors of the three types of vocational education, and the decision matrix is

$$A = \left(\mathrm{a}_{\mathrm{ij}}\right)_{3\times 5}. \tag{1}$$

– Secondly, the decision matrix should be transformed into a normalized matrix, and the data in the matrix should be processed according to the following formula:

$$Z_{ij} = \frac{\mathrm{a}_{\mathrm{ij}}}{\sqrt{\sum_{i=1}^{n} \mathrm{a}_{\mathrm{ij}}^{\ 2}}}. \tag{2}$$

The normalized matrix is $Z = \left(Z_{ij}\right)_{3\times 5}$.

Then the best alternative and the worst alternative are confirmed. The best alternative is $Z^{+} = Z_{i1\max}, Z_{i2\max}, ..., Z_{im\max}\big)$, and the worst alternative is $Z^{-} = \left(Z_{i1\min}, Z_{i2\min}, ..., Z_{im\min}\right)$, where $Z_{ij\min}, Z_{ij\max}$ represent respectively the maximum and minimum values of the object on the $j^{th}$ influence factor that needs to be evaluated.

Finally, the distance between the best and the worst conditions should be calculated for each evaluation object:

$$D_j^{+} = \sqrt{\sum_{i=1}^{m} \left(z_{\max} - z_{ij}\right)^2}. \tag{3}$$

$$D_I^{-} = \sqrt{\sum_{i=1}^{m} z_{\min} - z_{ij}\big)^2}. \tag{4}$$

In the formula, $i = 1,2,3$ represents the object being evaluated.

Then, the distance between each evaluation scheme and the best alternative is calculated, the result showing the degree of closeness between the two according to the equation:

$$C_1 = \frac{D_I^{-}}{D_I^{+} + D_I^{-}}, \tag{5}$$

where $C_1 \in \left(0,1\right)$. If $C_I$ is closer to 1, it means that the object of evaluation is closer to the best level. On the contrary, if $C_I$ is closer to 0, it means that the object of evaluation is closer to the worst level.

## 4. RESULTS ANALYSIS AND DISCUSSION

This paper describes a comparative study on the VE at PV enterprises and analyses the advantages and problems of the three modes of VE. Table 1 compares these three kinds of VE at PV enterprises. As can be seen from the table, the three modes have their own strengths and weaknesses, among which the cooperative education involving enterprises, universities and government has the longest development history, but practical results of this kind of VE are not so satisfactory. The engineering-centre-based VE and the cooperative education involving a number of enterprises and based on modern information technology and platform gain similar scores, which indicates that they are

**Table 1. Comparison of three vocational education modes in pv industry**

| Mode | Advantage | Disadvantage | C |
|---|---|---|---|
| The cooperative education mode based on modern information technology and platform | Resource sharing, cost reduction, cooperation and development of a multi enterprise | The distribution of interests, rights and interests between enterprises | 0.65 |
| Three party interaction VE mode involving the enterprise, university and government | The professional quality of employees is systematically cultivated, and their development is guaranteed. | Tripartite relationship isn't easy to coordinate, the staff cultivated doesn't meet the requirements of the times | 0.52 |
| VE mode based on engineering centre | Enterprises can get more resources, which is more in line with the needs of enterprises. | The cost is high, a large number of funds need to be provided, enterprises and schools should cooperate with the engineering centre. | 0.67 |

more suitable for modern PV enterprises to carry out the VE for their employees. Enterprises can choose a suitable one according to their own specific circumstance and make proper improvements.

The author chose a PV enterprise to carry out the VE experiment. For objective reasons, the author chose the enterprise cooperation VE based on a modern information technology and platform as the study object. Fig. 4 shows how the employees and managers of multinational corporations think about the VE they received based on a modern information technology and platform. As can be seen from the data, more than a half of the employees are satisfied with this kind of VE, and express that the arrangements are more humane both in time and space. However, some employees believe that this mode doesn't meet the needs of VE, and the managers think that this mode meets only some of the enterprises needs and it is not fully capable of training senior personnel, and needs to be improved further.

## 5. CONCLUSIONS

With the continuous development of PV enterprises, the demand for technical, management and research personnel in PV industry is increasing, and the traditional VE at PV enterprises fails to meet the needs of enterprises. Therefore, this paper reviews the research on the VE at PV enterprises and describes its current research state and the problems that exist in the traditional VE. It also analyses the necessity to innovate VE at PV enterprises in China and explores the new modes of VE for training PV enterprises employees. By analysing the data collected with TOPSIS, it can be concluded that the cooperative VE based on a modern information technology and platform, the cooperative VE involving the enterprise, university and government, and the engineering-centre-based VE – all of them can effectively improve the training speed of PV talents, and the multinational cooperative education model based on a modern information technology and platform is more suitable for a vast number of small and medium-sized PV enterprises, since it can offer for enterprises opportunities to share resources, reduce training costs and cultivate talents needed by enterprises. However, it needs to be pointed out that these three education modes still have their deficiencies and need to be improved further.

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# AN EVOLUTIONARY GAME SIMULATION OF PHOTOVOLTAIC ENTERPRISE'S TECHNOLOGICAL INNOVATION IN CHINA

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**ABSTRACT**

Developing photovoltaic industry is an important way of adjusting and optimizing the energy structure in China. Technological innovation behaviours of government and photovoltaic enterprises are analysed in this paper in line with evolutionary game theory. In addition, this paper discusses dynamic evolutionary process of stakeholders' behaviour and interaction, and uses MATLAB software to simulate this process. Results show that stronger interests from both sides are along with fewer costs and larger gains, which will also make it easier for the system to reach ideal conditions. Therefore, the government should reasonably control incentive behaviours of enterprises' scientific and technological innovations, because excessive incentives will lead to enterprises' obsession with economic interests, which ultimately puts both sides into a bad lock state.

Keywords: technology innovation, photovoltaic enterprise, evolutionary game theory

## 1. INTRODUCTION

Chinese government attaches great importance to scientific and technological innovations in photovoltaic technology trade, particularly, in energy conservation, energy efficiency, and utilization of renewable energy [1]. A photovoltaic enterprise is the main technological innovation body, so we must accelerate technological innovation pace to solve problems in that field [2, 3]. The development of enterprises' scientific and technological innovation is not only a long-term strategic task for constructing a new country, but also the key to further implementing strategies of innovation-driven development [4]. The innovation of enterprises is related to the optimization of regional industrial structure, the promotion of market competition and the formation of regional comprehensive innovation advantages [5, 6]. It will enhance countries' and regions' competitiveness, and it is the key to national policies implementation.

To address conflicts between economic development and environmental resources many countries have paid attention to renewable resources, such as solar energy. Nowadays, China's photovoltaic industry has become one of the world's ten major manufacturing industries [7]. Technological innovations at photovoltaic enterprises are of great uncertainty in many aspects, and there are many uncontrollable factors in technology innovation, products development, production and sales. The ultimate success of technological innovation is also unpredictable, so photovoltaic enterprises' technological innovation decisions become more and more important [8]. There are many documents on government' policies in supporting scientific and technological innovations, some of which are foreign studies on policies in supporting scientific and technological innovations of small and medium-sized enterprises (SME). In those studies, they explored technological innovation's impacts on SME, and pointed out that it

was funds shortage, backward technology and lack of talents that hindered enterprises' innovations [9]. Some scholars have studied factors, including enterprise scale, growth stage, enterprise's primary level, institutional environment, government support, leaders' characteristics, innovation model, and so on, that affect enterprises' innovation abilities [10–12]. In studying what government can do to support SME in scientific and technological innovation, some scholars put forward that we should rearrange and optimize scientific and technological innovation policy systems of such enterprises. They also believe that through policy intervention government can promote enterprises' independent innovations and break comparative advantage trap [13, 14]. In addition, there are researches on the input and output of government's support for SME scientific and technological innovation. For example, there is a research on relations between government R&D input and SME patent output [15]. By studying relevant literature, we can see that most studies are based on a comprehensively rational analysis, and that there are few studies using game theory to expound government' support for enterprises' technological innovation. However, in reality, there are always limitations on people's rational abilities, so stakeholders can hardly make decisions in a completely rational state.

Technological innovation policies refer to series of public policies of enterprises' technological innovation activities, released by a country, which can influence or change the directions of technological innovation. These policies are to create a favourable external environment for technological innovation and to overcome uncertainties in the process of technological innovation. By nature, photovoltaic enterprises' innovative achievements are public goods, and their innovative activities have positive externality, which means benefits of photovoltaic enterprises' innovations are not exclusive. Therefore, countries and governments need to take effective measures to support and promote individual's innovative activities.

## 2. METHODOLOGY

### 2.1. Basic Assumptions

***Hypothesis 1:*** Subject in evolutionary game is not just the behaviour of individuals but the population behaviour, randomly selected from a large population that repeatedly play games in accordance with biological or social way.

**Table 1. Revenue payment matrix of government and SME**

| Government | Enterprise | |
|---|---|---|
| | **Innovations (m)** | **No innovation (1-m)** |
| Incentive (n) | (C1+K1-W1, C2+K2-W2+E2) | (–W1, E2) |
| No incentive (1-n) | (C1, C2-E1-W2) | (0, 0) |

***Hypothesis 2:*** SME can choose innovation strategies or no innovation strategies. Innovation strategies include active cooperation with government incentive policies, investing in technological innovation and carrying out massive scientific and technological innovation.

***Hypothesis 3:*** Evolutionary game theory presumes that two players' rationalities are limited and the ultimate goal is to maximize their own interests.

***C1*** means: government' basic income under no incentive strategy; ***C2*** means: enterprises' intangible benefits under no incentive strategy.

***K1*** means: the total revenue generated by the government under incentive strategy; ***K2*** means: the total income obtained by enterprises under incentive strategy.

***W1*** means: the capital investment for SME incentive innovation under incentive strategy; ***W2*** means: the cost for SME to carry out scientific and technological innovation.

***E1*** means: companies suffered economic loss of revenue for the government; ***E2*** means: active mechanism and indirect income obtained by enterprises. With an inactive government, in order to carry out scientific and technological innovation, enterprises not only make investments, but also should bear the losses resulting from their enthusiasm, which leads to less gain than costs. Therefore, in the long run, ***C2< E1+ W2***. From the above analysis, we can get the payment matrix between government and SME, Table 1.

### 2.2. Local stability of equilibrium

Government interest subjects choose incentive and non-incentive strategy, when the revenue ex-

**Table 2. The determinant and trace of local equilibrium**

| Local equilibrium point | J determinant | Symbol | J trace | Symbol | Result |
|---|---|---|---|---|---|
| O(0,0) | $W_1$（$W_2$+$E_1$-$C_2$） | + | -$W_1$-$W_2$-$E_1$+$C_2$ | — | ESS(evolutionarily stable strategy) |
| A(0,1) | ($K_1$-$W_1$)($W_2$+$E_1$-$C_2$) | + | $K_1$-$W_1$+$W_2$+$E_1$-$C_2$ | + | Instable |
| B(1,0) | $W_1$($C_2$+$K_2$-$W_2$) | + | $W_1$+$C_2$+$K_2$-$W_2$ | + | Instable |
| V(1,1) | ($K_1$-$W_1$)($C_2$+$K_2$-$W_2$) | + | -$K_1$+$W_1$-$C_2$-$K_2$+$W_2$ | — | ESS(evolutionarily stable strategy) |
| P(m*, n*) | -mn($K_1$-$W_1$) ($C_2$+$K_2$-$W_2$) | — | 0 | | Saddle point |

pectation function $\alpha_{11}$, $\alpha_{12}$ and the average expected return $a_1$ are respectively as follows:

$$\alpha_{11} = m(C_1 + K_1 - W_1) + (1-m)(-W_1), \tag{1}$$

$$\alpha_{12} = C_1 m, \tag{2}$$

$$\alpha_1 = \alpha_{11} n + \alpha_{12}(1-n). \tag{3}$$

From the above results, we can get the dynamic copy equation of the government interest body:

$$F(n) = n(1-n)(K1m - W1). \tag{4}$$

As the first derivative of the $F(n)$, we can get:

$$F'(n) = (1-2n)(\mathrm{K}_1 m - W_1). \tag{5}$$

In the same way, the income expectation function of the enterprise choice of innovation and non-innovation strategy ($b_{11}$ and $b_{12}$ respectively) and the average expected profit $b_1$ are respectively as follows:

$$\beta_{11} = (C_2 + K_2 - W_2 + E_2)n + \\ + (\mathrm{C}_2 - E_1 - W_2)(1-n), \tag{6}$$

$$\beta_{12} = E_2 n, \tag{7}$$

$$\beta_1 = \beta_{11} m + \beta_{12}(1-m). \tag{8}$$

From the above, we can obtain the dynamic equation for the enterprise:

$$G(m) = m(\beta_{11} - \beta_1). \tag{9}$$

As the first derivative of $G(m)$, we can get:

$$G'(m) = (1-2m)[(K_2 + E_1)n + \\ + C_2 - W_2 - E_1]. \tag{10}$$

If $G(m)$=0, the solution for 3 stable state points are as follows:

$$\mathrm{m1}^*=0,\ \mathrm{m2}^*=1,\ \mathrm{n}^*=\frac{W_2 + E_1 - C_2}{K_2 + E_1}. \tag{11}$$

Five local equilibrium points of the game matrix can be obtained by the above calculation procedure: (0,0), (0,1), (1,0), (1,1), *(m*, n*)*. Among them, (0,0), (0,1), (1,0) and (1,1) are for four pure strategy equilibrium points, and *(m*, n*)* point is the mixed strategy equilibrium point.

## 3. RESULTS ANALYSIS AND DISCUSSION

### 3.1. Discussion of evolutionary game stability parameters

Functions *f(n)* and *G(m)* constitute the dynamic replication system of government to support the game of science and technology innovation of SME. The stability of the equilibrium point of the system is judged by the local stability of the Jacobian matrix, and the properties of the five equilibrium points are tested according to an analysis method. The equilibrium point is added to the Jacobian matrix *J*, and its stability is analysed. The results are shown in Table 2.

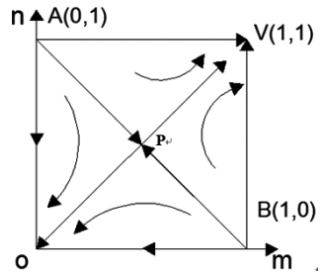


Fig. 1. Phase diagram of the game between the government and SME

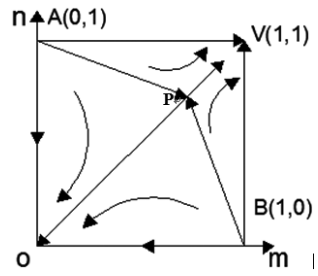


Fig. 2. Other parameters unchanged, K1, K2 decreased

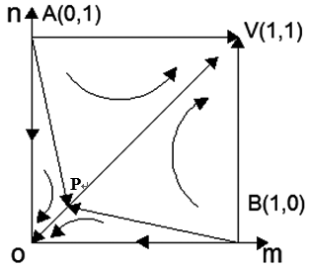


Fig. 3. Other parameters unchanged, *W1, W2* decreased

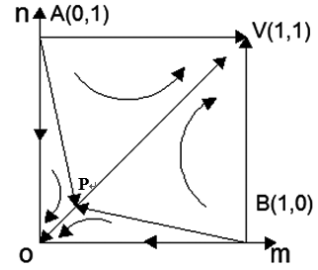


Fig. 4. Other parameters unchanged, $E_1$ decreased

In Fig. 1, A, P and B are the three points that make the game system converge to different strategies. When the initial state of the parties involved in the behaviour of game strategy is in the APBO region, the final results of the game will converge to the (innovation, incentive) stable strategy; when the initial state of the parties involved in the behaviour of game strategy is in the APBV region, the final results of the game will converge to (do not create new incentives, not stable) strategy combination. According to the payoff matrix of Game 1 in the table, we can see that the income of both sides of the game (innovation, incentive) is higher than that of the stable strategy.

Therefore, in order to make the game equilibrium converge to an ideal state, it should make the saddle point P shift to the left, the area APBV to increase, converge to the strategy (innovation, incentive) and decrease the probability of convergence to the strategy (no innovation, no incentive). On the contrary, the probability of convergence to the strategy (innovation, incentive) decreases, while the probability of convergence to – (no innovation, no incentive) increases.

### 3.2. Influence of parameter variation on convergence rate

The best response dynamics in the game is with stakeholders' myopia (Myopic Best Dynamic). The initial state in the customary way influences the behaviour of game participants, and eventually it decides to move in the direction of the main interests balancing strategy. Specific analysis is as follows.

Firstly, assuming that other parameters are constant, the income obtained by the government and SME would be reduced. That is, *K1* and *K2* are reduced, which will lead to an increase of $\frac{W_2 + E_1 - C_2}{K_2 + E_1}$ and $\frac{W_1}{K_1}$, the $X$ and $Y$ coordinates of the saddle point $P$ are increased, and the regional APBO area increases, area APBV decreases, and the initial state shifts into a higher probability region of APBO, eventually making the probability of converging to the strategy (innovation, incentive) reduce, and the probability of converging to the strategy (no innovation, no incentive) increases, as shown in Fig. 2.

Secondly, assuming that parameters are the same, when $W_1$ and $W_2$ decrease, it will lead to a decrease of $\frac{W_2 + E_1 - C_2}{K_2 + E_1}$ and $\frac{W_1}{K_1}$, and the $X$ and $Y$ coordinates of $P$ saddle point are reduced, so that the regional APBV area increases, APBO area decreases, and the initial state shifts into a higher probability region of APBV, eventually making the probability of the system converging to the strategy (innovation, incentive) increase, and the probability of converging to the strategy (no innovation, no incentive) reduce, as shown in Fig. 3

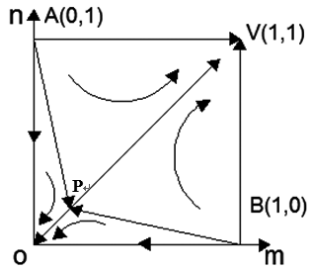


Fig. 5. Other parameters unchanged, *C2* decreased

Thirdly, assuming that parameters are the same and $E_1$ is reduced, the abscissa $\frac{W_2 + E_1 - C_2}{K_2 + E_1}$ of the saddle point of *P* is reduced, so that the area APBO increases and area APBV decreases. Therefore, the probability of initial state, as regional APBV, increases. Finally, the system converges to the increase of the probability of the strategy (innovation, incentive). The convergence to the strategy (no innovation, no incentive) probability decreases. It is shown in Fig. 4.

Fourthly, assuming that parameters are the same, and making the abscissa of the saddle point *P* to decrease, and the saddle point *P* moving to the left, the regional APBO area will decrease, and APBV area will increase. The initial state will move into increased probability of regional APBV. Finally, the system converges to the increase of the probability of the strategy (innovation, incentive). Then in case (no innovation, no incentive) the probability of convergence to the policy decreases, as it shown in Fig. 5.

### 3.3. Simulation experiment

In this paper, MATLAB software is used to simulate the evolution path and the final equilibrium state of the game between the government and enterprises. The results are as follows.

Firstly, it is the influence of the initial population proportion change on the evolution results. The horizontal axis represents time, and the vertical axis represents both sides' main choice of technological innovation strategy proportion, namely, the government and SME technological innovation choice intentions. Parameter values are: $W_1$=1.5, $W_2$=1, $K_1$=2.5, $K_2$=1.5, $E_1$=1.5, $C_2$=1. M0 and N0, respectively, represent the SME and the government's initial choice of incentive and technological innovation behaviours. Fig. 6 shows the evolution path

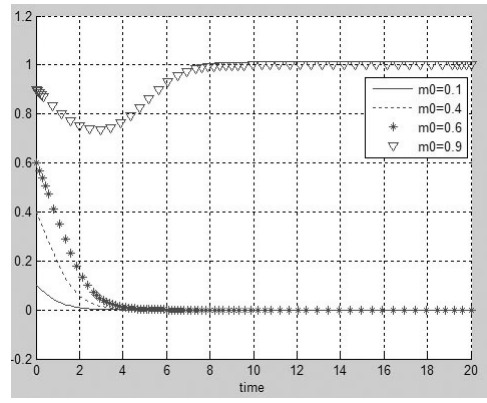


Fig. 6.The influence of different initial intention on the evolution results

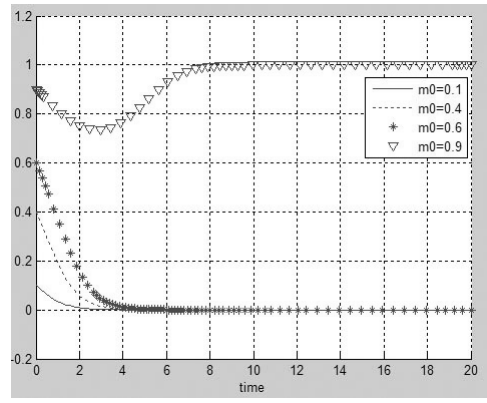


Fig. 7. The impact of government investment on the evolution

time dependence and evolution of the choice of science and technology innovation behaviours under different initial states.

Secondly, it is the impact of government input on the evolution of the results. Numerical simulation results are shown in Fig. 7. The strategy for SME to select scientific and technological innovation is 0.8. The government investment in science and technology innovation is not always the bigger the better. The government's excessive investment will enable the probability of enterprises technological innovation behaviour reduce to 0.

Thirdly, it is the influence of the change of government's main body on the evolution of the comprehensive income. Numerical simulation results are shown in Fig. 8. The strategy for SME to select scientific and technological innovation is 0.8. Under the incentive policy of the government, the greater the value-added benefits of enterprises in scientific and technological innovation, the easier the choice of the incentive strategy. Therefore, a larger amount of incentive and funding can encourage enterprises to actively carry out scientific and technological in-

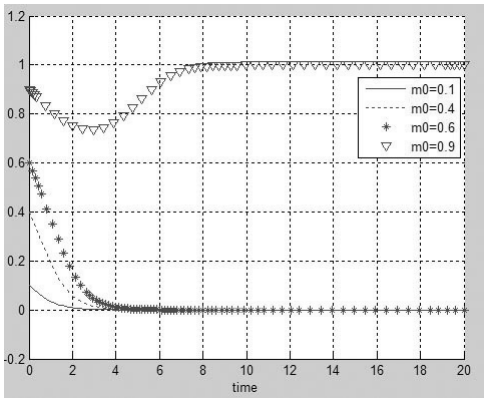


Fig.8.The influence of the change of government interest on the evolution results

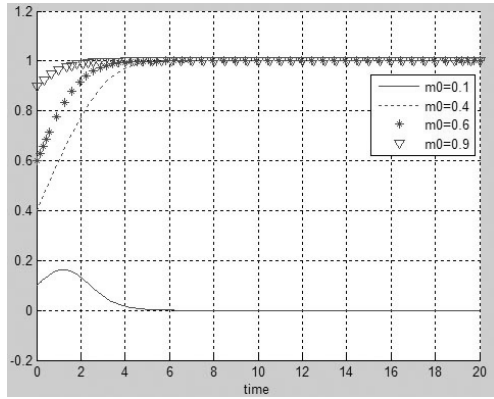


Fig.9.The loss of enterprises' choice of innovation strategy

novation activities, and ultimately leads to a win-win situation.

Fourthly, it is the impact of the loss on the evolution of SME choice of science and technology innovation strategy. Numerical simulation results are shown in Fig. 9, and the strategy of enterprise's choice of scientific and technological innovation is 0.8. The greater the degree of loss in business, the deeper will the enterprise and the government evolve into a bad stable strategy (no incentive, no innovation), because the SME choice of technological innovation behaviour is based on government incentives and the need to invest more funds. This time, to reduce a negative influence of business strategy, a more conservative strategy will be favoured, that is to choose non-innovation.

### 3.4. Policy suggestion

Enterprises' enthusiasm in scientific and technological innovation depends on the proportion of government incentives and scientific and technological innovation. Therefore, we put forward the following recommendations.

Firstly, we should establish a long-term mechanism of scientific and technological innovation, and improve the scientific and technological innovation consciousness. According to the results of the game, the system will evolve into the ideal state of technological innovation of SME and government incentives. Improving the proportion of the government incentives will actively develop a reasonable initial incentive policy and technological innovation. In addition to reasonable funding and incentives, government agencies should increase publicity efforts to promote technological innovation, create a strong atmosphere of scientific and technological innovation, and effectively improve scientific and technological innovation awareness.

Secondly, we should strengthen the evaluation of scientific and technological innovation achievements, and set up a reasonable incentive mechanism. According to the results of the game, the government's investment in science and technology innovation is not as large as the cost of funding. Too much monetary supports in technology innovation might cause poor quality, so governmental and scientific institutions shouldn't blindly support all enterprises. Priority support should go to institutions and SME with independent intellectual property rights and good economic and social gains.

Thirdly, we should improve the quality of scientific and technological innovation, and increase the income from scientific and technological innovation. According to the results of the game analysis, we can see that increasing the government income from the scientific and technological innovation achievements will greatly encourage SME enthusiasm for innovation. Technological innovation of SME can be transformed into productivity, so as to promote social progress and benefit the government, which, in turn, will increase government's support for SME in science and technology innovation. In addition, it will help to realize protective intentions and to reach a win-win situation. Moreover, technological innovation of SME should not only focus on the advanced ones, but on improving the overall research levels at large.

Fourthly, we should improve the top-level design of implementation of scientific and technological innovation policy, and strengthen the protection of intellectual property rights. Practical experience shows that under market economy, tax is an important means to support technological innovation of SME, especially for developing countries,

which are at a stage of rapid economic development. Tax policy, one of the most effective resource allocation policies, can effectively mobilize the enterprise technological innovation, promote scientific and technological progress, and accelerate the optimization of industrial structure. Intellectual property rights play an important role in promoting and maintaining scientific and technological innovation, but the protection of intellectual property rights has been a weak link in China. Constructing a perfect, efficient and strict intellectual property protection system will conduce to creation of a social environment that respects the achievements of scientific and technological innovation.

## 4. CONCLUSION

To carry out technological innovation of photovoltaic enterprises, we must first wake leaders' innovative consciousness. Under limited rationality condition, this paper constructs an evolutionary game model of government and enterprises in the choice of scientific and technological innovation behaviours. The enterprises' enthusiasm in scientific and technological innovation depends on government incentives and the proportion of scientific and technological innovation. Based on the hypothesis of bounded rationality and using the evolutionary game theory, this paper constructs a replication dynamic model of asymmetric evolutionary game analysis of stakeholders in science and technology innovation. Results show that stronger interests from both sides are along with fewer costs and larger gains, and the system can reach ideal conditions easily. Therefore, the government should reasonably control incentive behaviours of enterprises' scientific and technological innovation, because excessive incentives will cause enterprises' obsession with economic interests, which ultimately leads both sides into a bad lock state.

According to the analysis, government' investment in science and technology innovation is less than the cost of funding. Too much monetary supports in technology innovation might cause poor quality, so the government and scientific institutions shouldn't blindly support all enterprises. Priority support should go to institutions and SME with independent intellectual property rights and good economic and social gains. In performance evaluation, the government cannot simply take the science and technology innovation as the only standard in measuring government's comprehensive strength.

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# EARLY WARNING AND PREVENTIVE MEASURES FOR FINANCIAL RISKS OF LED LIGHTING ENTERPRISES

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**ABSTRACT**

In recent years, due to intensified competition in the external market and poor internal management of LED industry, the phenomenon of financial crisis has become common for solar enterprises in China, and some of them even went bankrupt. In order to develop in a fierce competition environment, many solar lighting enterprises have set up financial risk pre-warning systems. This paper is based on this background and purpose. The definition of basic concepts related to LED industry financial risks and traditional financial forewarning methods are discussed. Using the analytic hierarchy process of enterprise financial risk early warning on China's solar energy enterprises add to the status quo of the enterprises management and the risk analysis of lighting enterprises. And the feasibility of this paper is demonstrated and verified by practical examples.

**Keywords:** financial early warning, analytic hierarchy process, solar energy lighting enterprises

## 1. INTRODUCTION

With the enhancement of people's awareness of energy conservation and environmental protection, solar lighting enterprises are developing rapidly. However, as an enterprise is an artificial system and organism, its existence and development are always with various risks [1]. Financial risks affect the survival and development of enterprises to a great extent. Therefore, in order to make solar lighting enterprises to develop healthily and orderly, and to have an invincible position in the competition, the primary problem of enterprise development is to effectively carry out early warning of enterprise financial risk and to guard against it [2]. Solar energy lighting enterprises in China have developed rapidly. However, most of them are eager to develop further and ignore the risks, and there is no risk warning or prevention mechanism. Any market mutation, capacity expansion, technological updates, environmental protection and other factors will bring financial pressure on the enterprise and will lead to further financial risks. Therefore, it is most urgent to establish an effective early-warning system of financial risks. As long as the reasons for the deterioration of financial conditions are found in time, operators can take preventive and control measures in a timely manner, so as to avoid the expansion of financial risks [3]. For enterprises in the supply chain of LED industry, based on risk early warning results, the supplier can judge the business development of the enterprise, so as to formulate the corresponding credit policy and the collection policy, guarantee the receivable account to recover in time and reduce the bad debt loss, and at the same time the seller can judge whether the supply can be provided in time [4]. Economic benefits and personal development of every employee in LED enterprises are closely related to the operation and development of enterprises themselves. When enterprises are in trouble, employees can make reasonable suggestions for enterprises and help enterprises to get out of difficulties [5].

## 2. STATE OF THE ART

### 2.1. Research on risk theories at home and abroad

There are three kinds of views on the risk identification in foreign financial theoretical researches. The first one is the «risk loss» when risk arises from the uncertainties of the real world and the finiteness of human understanding of the real world. The reason to explain human's cognition of risk is that risk is usually related to economic loss. Some scholars believe that risk is the possibility to encounter misfortune or catastrophe. Secondly, «the differences between results» – there is always an expected goal for the development of everything. However, due to the changes of external conditions, there is usually a deviation between the goal achieved and the expected one. A negative deviation between the expected target and the actual target is usually identified as a risk. The third kind of risk is «the uncertainty». «Objective uncertainty» is an explanation given to risk by American scholars [6].

From the late 1980s and early 1990s, China began to carry out researches on financial risk. It is considered that financial risk is the risk of enterprise's ability to pay the principal and interest caused by different enterprise investments. The larger the enterprise financial leverage coefficient is, the greater the financial risk will be. Enterprises without liabilities are believed not to be at financial risks. Scholars call this risk a funding risk or a debt financing risk. It is also viewed as a financial risk in a narrow sense [7].

### 2.2. Researches on the application of financial risk early warning index and model in China and abroad

Early in the 1930s, foreign scholars began to conduct quantitative researches on corporate financial early warning, which mainly focused on the establishment of an early warning model. The main research methods are: firstly, the statistical method. Researchers found that the most important factors in judging enterprises risk profiles are enterprise size, financial structure, liquidity and business performance. Secondly are the non-statistical methods. Along with the continuous development of statistical technology and information technology, technologies like the efficiency coefficient method, fuzzy

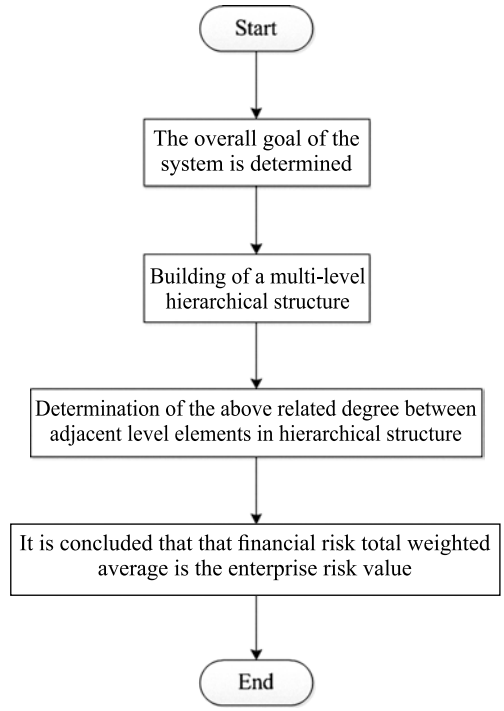


Fig. 1. Operating steps of the analytic hierarchy process

algorithm and artificial neural network are gradually introduced into the study of financial risk early warning. Artificial neural network is applied to the study of financial risk early warning. It is found that the accuracy rate of the model is 91 %, which is obviously higher than those of other discrimination methods. This model can accommodate a certain amount of errors and is able to learn from and correct mistakes. Besides, there are no strictly postulated conditions for the use of it, so it is widely used today [8]. Randomness is a fatal weakness of neural network systems. It is necessary to debug it repeatedly so as to get a better neural network structure. It is very laborious and time consuming, so its application has been greatly restricted.

The results of foreign researches have provided basic theoretical framework and methodological system for researches on financial risk early warning and preventive measures for Chinese enterprises. However, foreign researches focus on quantitative studies only and ignore a qualitative analysis. In addition, due to the differences in national laws, political environment and economic development of different countries, some of the research results are not necessarily appropriate for China's enterprises. So warning methods need to be adapted to China's actual situation, development condition and industry characteristics, so as to form a financial risk early warning system for Chinese enterprises.

Most of Chinese current financial risk warnings are based on just one warning method. In the determination of a comprehensive early warning index, expert scoring method with strong subjectivity is used. All indicators are treated with equal weights. There are many defects in the current Chinese researches: firstly, there are too many indicators in the financial risk early warning index system, some of which are repetitive. Secondly, the artificial determination of financial indicators can't objectively reflect the impact of risk warning indicators on risks [9]. Thirdly, researches are limited to financial risk early warning of «special processing» enterprises. Researches on financial risk early warnings of other enterprises don't include any systematic theoretical analysis, for no clear theoretical framework and implementation method have been formed.

## 3. METHODOLOGY

### 3.1. Definition of financial risk and financial risk early warning

As a participant and a competitor in the market economy, the concept of financial risk mainly has two aspects. First one is the generalized financial risk. The impact of various uncertainties will make the company's financial results deviate from the expected ones and bring about risks. Problems that appear in the process of enterprise's management may change the risk into economic loss and decrease the solvency and profitability of the enterprise [10]. Secondly, the narrow sense financial risk. The uncertainty with which an enterprise uses monetary funds to pay off debts is called financial risk. Financial risk is related to corporate debt management, and financial risk is only caused by the repayment of principal and interest.

As business is influenced by a variety of internal and external factors, this paper agrees with the concept of a financial risk in a broad sense. In the course of business, due to the factors, such as uncontrollable changes of external business environment and frequent changes of internal operating conditions, financial risks of an enterprise will reduce the efficiency of the value movement, and the actual operating performance will deviate from the expected goal. All of these will finally have adverse effects on the business and finance of the enterprise.

Based on accounting information and other relevant information, financial risk warning uses a series of scientific systems analysis processes and methods, establishes a corresponding index system, and uses relevant theories of accounting, statistics and economics to analyse comprehensively the solvency, profitability, operation ability and development ability of the enterprise, predict the financial status of the enterprise and find out financial and other risks in the production and operation of the enterprise. Relevant personnel and departments will thus be warned before the crisis advent and be urged to take measures to avoid the financial crisis [11].

Enterprise financial risk early warning system aims to establish a mechanism, by which enterprise's investors and managers would notice the signal of financial deterioration in advance, and thus take corresponding measures to keep the enterprise invincible in the fierce competition. Based on financial accounting information, financial risk early warning uses a mathematical model to establish an early warning model and to identify the financial risk of the enterprise through the establishment of enterprise financial index system.

### 3.2. Financial risk early warning method – analytic hierarchy process

The analytic hierarchy process (AHP) decomposes decision-related elements into the hierarchical structure of the target layer, the criterion layer and the program layer, which will be analysed quantitatively and qualitatively. Then decision will be made to determine the weight of each index in multi-project and multi-scheme optimization decision problem. The operating steps are shown in Fig. 1.

Advantages of AHP can be reflected in the following aspects: firstly, the systematic feature. The object of AHP is a system which can be handled with analytical method through decomposition, comparison, judgment and integration. AHP has become one of the important tools for systematic analysis. Secondly is the practicality. By combining qualitative analysis and quantitative analysis, APH, with its wide application, can solve many practical problems that can't be solved by traditional optimization techniques. At the same time, this method enables decision makers to communicate with decision analyzers and increase the effectiveness of decision making. Thirdly is the conciseness. Calculations are simple, and the result is clear. It is convenient for the decision makers to under-

**Table 1. Financial risk early warning index system**

| | | |
|---|---|---|
| Financial index | Solvency *A* | Quick ratio $A_1$ |
| | | Asset – liability ratio $A_2$ |
| | | Interest protection factor $A_3$ |
| | Profitability *B* | PV module sales profit margins $B_1$ |
| | | Crystalline silicon conversion rate $B_2$ |
| | | Cost of profit margins $B_3$ |
| | Management ability *C* | Quality inspection pass rate $C_1$ |
| | | Total asset turnover rate $C_2$ |
| | | Inventory turnover rate $C_3$ |
| | Development ability *D* | Total assets growth rate $D_1$ |
| | | R&D expenses growth rate $D_2$ |
| | | PV component sales revenue growth rate $D_3$ |
| Non-financial index | Industry influence | |
| | Enterprise energy saving and environmental protection capability | |
| | Enterprise strategic management ability | |
| | Quality of enterprise leadership | |

stand the basic principle of AHP and master its operating steps.

### 3.3. Basis for early warning index selection

By determining the financial risk early warning indicators, meeting the requirements of principles of sensitivity, logic, particularity, effectiveness, objectivity, appropriateness and measurability, analysing Chinese and foreign literature, drawing lessons from the financial evaluation index system, which is widely used in the «performance evaluation rules for state-owned capital» promulgated by the Ministry of Finance and other four ministries, and consulting some senior executives of solar lighting enterprises, certified public accountants and auditors of accounting firms, as well as accounting professors, this paper confirms the financial indicators that can reflect corporate solvency, profitability, management capacity, and development capability, and non-financial indicators that can reflect enterprise industry influence, energy saving and environmental protection capabilities.

### 3.4. Design of early warning index system

Enterprise financial risk early warning starts from the construction of an index system. The application of AHP will eventually turn the target into a single directly-judged indicator. The selection of basic indicators is based on the content of the indicators and its influence on the overall target. As for the selection of specific indicators, indexes are complementary to each other, and they can't be repeated, which are not only representative, but also can reflect the operating conditions of enterprises. In this paper, AHP is used to study the factors that affect financial risks. AHP divides influencing factors into top, middle and bottom ones. The highest level, also known as the target layer, refers to the corporate financial risk in this paper. The middle layer, also known as the criterion layer, represents the middle layer index involved within the final goal. The key is the lowest specific warning indicator, which is also called the program layer. According to the principles of index system construction,

**Table 2. Data from balance sheets and income statements (unit: thousand yuan)**

| | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|
| Inventory | 811746 | 1261207 | 2040731 | 1665021 |
| Quick assets | 910549 | 3811701 | 4020402 | 6291454 |
| Current assets | 1722295 | 5072908 | 6061133 | 7956475 |
| Total assets | 2813461 | 7657579 | 11067796 | 16257105 |
| Current liabilities | 649002 | 1519577 | 2829419 | 6939388 |
| Total liabilities | 1339878 | 2859346 | 4895526 | 8071246 |
| Net assets | 1473583 | 4798233 | 6172270 | 8185859 |
| PV components revenue | 1530585 | 4015788 | 7445790 | 7158441 |
| Operating income | —— | 4059323 | 7553015 | 7254869 |
| PV components cost | 1100372 | 2971710 | 5713605 | 5458284 |
| PV components business profit | 430213 | 1044078 | 1732185 | 1700157 |
| Interest expenses | —— | 65945 | 162131 | 376336 |
| Income tax expense | —— | 12928 | -5588 | -31831 |
| Total cost | —— | 3465874 | 6611474 | 7739430 |
| Debit | —— | 659394 | 1103669 | -108225 |
| Gross profit | —— | 593449 | 941538 | -484561 |
| Net profit | —— | 580521 | 947126 | -452730 |

this paper constructs a financial risk early warning index system, which is shown in Table 1.

Industry influence affects the business in a comprehensive manner, including the impact of the enterprise on the regional or the entire industry, its leading role, its public image and so on. Enterprises with great industry influence have a smooth relationship network and have social resources, which can easily resist the risk. The capability of energy saving and environmental protection can be attained by the performance of new energy enterprises. The energy saving and environmental protection capacities of enterprises consist of the capability of resources consumption and environmental protection. Enterprises should implement full-range energy conservation and environmental protection concerning product design, research and development, production, sales, logistics and so on. Improving the strategic management capability can help enterprises to gain the initiative to master the overall situation, improve the risk-resistant ability, so that they can defeat other competitors in the fierce competition and achieve sound development for them. In the face of intensified market competition, more and more people think that the quality of enterprise leadership is related to the success or failure of the enterprise, which has an impact on the achievement of enterprise's strategic objectives and its core competitiveness. With highly qualified corporate leaders, business can be smoothly managed, performance can be relatively enhanced, the ability to resist financial risks can be improved and financial risks can be reduced.

## 4. RESULTS ANALYSIS AND DISCUSSION

Taking a solar energy lighting enterprise "A" as an example, an experiment on the application effect of financial risk early warning system was carried out.

Financial indicators were based on data selected from balance sheet and the income statement of a company in years 2006, 2007, 2008, 2009 and on internal financial data that are shown in Tables 2 and 3.

Non-financial indicators are drawn by adopting expert scoring method. The board of directors,

**Table 3. Financial ratios**

| % | 2007 | 2008 | 2009 |
|---|---|---|---|
| Quick ratio | 251 | 142 | 91 |
| Asset – liability ratio | 37 | 44 | 50 |
| Interest protection factor | 10 | 6.8 | - 0.29 |
| PV module sales profit margins | 26 | 23 | 24 |
| Crystalline silicon conversion rate | 13.5 | 17.3 | 17.5 |
| Cost of profit margins | 17.1 | 14.2 | -6.3 |
| Quality inspection pass rate | 93 | 96 | 97 |
| Total asset turnover rate | 0.77 | 0.81 | 0.53 |
| Inventory turnover rate | 2.87 | 3.46 | 2.95 |
| Total assets growth rate | 172 | 45 | 47 |
| R&D expenses growth rate | 20 | 30 | 5 |
| PV component sales revenue growth rate | 162 | 85 | -3.8 |

**Table 4. Non-financial indicators scoring**

| | 2007 | 2008 | 2009 |
|---|---|---|---|
| Industry influence | 0.4 | 0.6 | 0.6 |
| Enterprise energy saving and environmental protection capability | 0.6 | 0.8 | 0.8 |
| Enterprise strategic management ability | 0.8 | 0.8 | 0.6 |
| Quality of enterprise leadership | 0.6 | 0.8 | 0.8 |
| Average | 0.6 | 0.75 | 0.7 |

board of supervisors and members of the finance directorate, project directors and other middle-level managers and staff representatives score the following non-financial indicators. The result is shown in Table 4.

The underlying index dimensionless processing results are multiplied by the corresponding weights, and the middle layer index value is obtained. The bottom layer index values of the dimensionless index are multiplied by the corresponding weights, and then the final target value is obtained. Indicator calculations results are shown in Table 5. Under normal circumstances, it is quite reasonable that the result is at the level of intermediate value.

It can be seen from the Table 5 that the financial situation of the solar energy lighting enterprise "A" is in a state of greater risk, which is mainly reflected by low scores of the profitability index and solvency index. Firstly, influenced by the international financial crisis, countries reduced subsidies in solar energy illumination, and photovoltaic (PV) products prices fell sharply. The decrease in sales income and net profit resulted in a significant reduction of interest rate, asset turnover rate, and profit margin of main business of the company "A". The main business income growth rate and the main business profit growth rate are negative. Secondly, the increase in international freight costs led to an increase in sales expenses. The increasing investment in R&D investment, the expansion of the management structure and the growing number of employees gave rise to substantial increase in the cost of business and to the decline of company "A" profits. As a result, the cost of profit margins has dropped.

## 5. CONCLUSIONS

In today's fierce market competition, any enterprise should be ready for financial crisis. It is of great significance for enterprises to carry out financial risk early warning and prevention research. For the enterprise, it can reduce unnecessary economic losses for its sound development, while for the society as a whole it can improve the operating environment. In this paper, after in-depth study, the following conclusions were drawn with China's solar energy lighting enterprises as the research object.

The financial risk early warning system in line with solar lighting enterprises characteristics includes financial indicators and non-financial indicators. The financial indicators are composed of four aspects, that is, solvency, profitability, operation ability and development ability, and twelve index systems. The non-financial indicators include the influence of the industry, capability of energy conservation and environmental protection, enterprise strategic management, and the quality of enterprise leadership. On this basis, a multi-level mo-

**Table 5. Indicator calculations results**

| Project | Weight | 2007 | 2008 | 2009 |
|---|---|---|---|---|
| Quick ratio $A_1$ | 0.296 | 0.296 | 0.296 | 0.296 |
| Asset – liability ratio $A_2$ | 0.165 | 0.165 | 0.165 | 0.134 |
| Interest protection factor $A_3$ | 0.539 | 0.539 | 0.539 | 0 |
| Solvency $A$ | 0.277 | 0.277 | 0.277 | 0.103 |
| PV module sales profit margins rate $B_1$ | 0.320 | 0.320 | 0.320 | 0.320 |
| Crystalline silicon conversion rate $B_2$ | 0.102 | 0 | 0.06 | 0.06 |
| Cost of profit margins $B_3$ | 0.558 | 0.558 | 0.558 | 0 |
| Cost of profit margins $B$ | 0.466 | 0.457 | 0.451 | 0.149 |
| Quality inspection pass rate $C_1$ | 0.165 | 0 | 0.165 | 0.165 |
| Total asset turnover rate $C_2$ | 0.297 | 0.136 | 0.151 | 0.047 |
| Inventory turnover rate $C_3$ | 0.538 | 0.279 | 0.392 | 0.295 |
| Management ability $C$ | 0.161 | 0.067 | 0.089 | 0.041 |
| Total assets growth rate $D_1$ | 0.165 | 0.165 | 0.165 | 0.165 |
| R&D expenses growth rate $D_2$ | 0.297 | 0.297 | 0.297 | 0 |
| PV component sales revenue growth rate $D_3$ | 0.538 | 0.538 | 0.538 | 0 |
| Development capacity $D$ | 0.096 | 0.096 | 0.096 | 0.016 |
| Financial indicators | —— | 0.901 | 0.913 | 0.309 |
| Financial indicators after weighting | 0.75 | 0.675 | 0.685 | 0.232 |
| Non – financial indicators after weighting | 0.25 | 0.15 | 0.188 | 0.175 |
| Total risk | —— | 0.825 | 0.872 | 0.407 |
| Risk level | —— | Risk-free | Risk-free | More risky |

del of enterprise financial risk early warning was set up. Questionnaires and analytic hierarchy process are applied to determine the weights of these indicators. Standardized processing methods and formulas for quantitative indexes are put forward. The calculation method and formula for the warning value are integrated. In view of the causes and early warning of the financial risk of solar lighting enterprises, this paper argues that the measures taken to prevent financial risks of such enterprises mainly include the establishment of financial risk early warning system and strengthening the management of enterprise information.

The financial risk early warning of solar energy lighting enterprises is a new exploratory research field. Therefore, it leaves much to be desired, such as the selection of early warning indicators, the object of the questionnaire, the processing of scoring results and so on.

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# FACTORS, FINANCIAL STRUCTURE AND FINANCIAL CONSTRAINTS OF LIGHTING LAMPS MANUFACTURING ENTERPRISES

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**ABSTRACT**

At present, there are two widespread opinions on the factors that affect financial constraints faced by enterprises. One opinion is that the enterprise's own factors are main determinants of financial constraints, and another is that the financial structure is the decisive factor of the financial constraints. Based on the current theoretical investigation of the factors that affect the financial constraints faced by enterprises, financial marketization indicators of various enterprises were analysed purposely to measure their corresponding financial structure. The measurement model was established based on data samples of the operating status, and regression analysis was undertaken to study the results. The data showed that the factors of the enterprise itself are more decisive than those of the financial structure. The research data presented in this paper provide a basis for the research and development of enterprise factors, financial structure and financial constraints.

**Keywords:** enterprise factors, financial structure, financial constraints, lighting lamps manufacturing enterprises

## 1. INTRODUCTION

Since the establishment of the central bank, the financial session on the monetary and financial policy debate has never stopped. With the rapid development of China's economy, economists from various countries around the world have been paying more and more attention to China's monetary policy, and at the same time have a lot of doubts about the economic policy [1]. This brings about the problem of financial restraints on enterprises in China. Financial constraints of enterprises mean that the enterprise' economic situation can't meet the needs of its development and even the maintenance of its funds. This is mainly manifested in two aspects: on the one hand, working capital lack in the short term [2]; on the other hand, funds for investment projects lack in the long term [3]. The reason for many enterprises in China having such financial constraint is mostly that financing channels and behaviour of the corporations are not smooth [4]. For example, difficulties with bank loans and the stock issue, broken capital chain, insufficient initial capital, difficulties with trade credit, and so on.

What are the factors that play a major role in the financial constraints of Chinese enterprises? There are three main theoretical schools, which are, enterprise factor theory, financial structure theory and institutional environment theory. The enterprise factor theory states that enterprise's features are the determining factor which mainly affects the financial restraint degree of the enterprise. These features include many aspects such as the asset structure, property right structure, scale, reform, credit record, investment demand, performance and corporate financing channels of the enterprise [5]. The financial structure theory states that the financial structure is the decisive factor that mainly affects the financial constraint degree of the enterprise. The financial structure of the enterprise includes the degree of enterprise competition, the degree of marketization of the financial market and the distribu-

tion of credit funds [6]. Institutional environment theory as the third theory is relatively new compared with the previous two. This theory states that the institutional environment of the enterprise is the main determinant of its financial constraints, and the institutional environment of the enterprise includes its legal policy and legal system [7].

As a result of the uncertainty of the factors affecting the financial constraints, and the need for facing up to these constraints, this paper makes a hypothetical test of the enterprise factor theory and the financial structure theory, which are relevant basic theories. Financial marketization indicators of various enterprises were analysed and measured corresponding to the enterprise's financial structure. Based on the sample data of the operating conditions, the econometric model was established, and the regression analysis was carried out.

## 2. STATE OF THE ART

It has been established in the theory of business factors that poor performance of a business will lead to the lack of sufficient financial support for this business, thereby leading to an increase in its financial burden [8]. And the business is well developed and attains outstanding performance when it reduces the financial resistance of bank loans and the financial burden on the enterprise by giving back the confidence of the bank's future capital [9]. The ability of the enterprise to issue stocks and bonds is also negatively correlated with the profitability of the enterprise. Some researchers also report that the degree of investment needs of the enterprise directly affects the degree of financial constraints of the company [10]. This is because for a certain amount of financial support, the greater the demand for investment, the heavier will be the burden on company's long-term investment funds and liquidity. Foreign researchers found that the record of good credit can not only enhances the visibility and reputation of the enterprise, but also helps the next round of financing, and thereby the burden of financial constraints can be reduced [11]. And the enterprise's asset structure is related to the size and structure of its collateral assets, affects its ability of corporate financing and having bank loans. The wider the financing channels are, the greater the amount of financing will be, and the smaller the financial pressure will be. Additionally, a larger amount of financing will also mean a greater degree of financial tension [12]. Some researchers pointed out that government support obtained by China's CCTV companies is much larger than that of other types of enterprises, and the reform of the tax system made the situation for local enterprises improved. The structure of property rights also plays an important role in the degree of financial constraints, which can be reflected as the state-owned enterprises being more likely to obtain policy loans and subsidies than non-state-owned enterprises. At the same time, the financial constraints of corporate property structure of the enterprise can also be reflected in its performance.

The literature on financial structure theory shows that in countries with relatively high financial development, enterprises that rely on external financing are developing at a faster rate, which is mainly because of their low financial constraints. There are also studies showing that companies with higher financial constraints and slower growth are more likely to ease financing difficulties due to the development of the financial industry [13]. Researchers studied the relationship between the degree of marketization of financial industry and the pressure of corporate finance. The results showed that the competition of enterprises in financial industry is intense. The higher the degree of marketization, the higher the marketization of credit funds and the better the development of the financial industry, leading to a reduction in financial pressure on the enterprise. At the same time, there are also the results of many researchers that agree with this point of view.

## 3. METHODOLOGY

On the basis of the relevant theory, lighting lamps manufacturing enterprises were taken as the sample. This paper analyses the influence of enterprise factors and financial structure on the financial constraints of enterprises by using the method of post-hypothesis verification.

### 3.1. Research hypotheses based on related theories

Firstly, the enterprise factor theory was assumed. Factors such as capital structure, ownership structure, scale, reform, credit records, investment demand, operating performance and financing channels, departments, etc. were shown to have

a decisive effect on the degree of financial constraints faced by enterprises.

Secondly, the financial structure theory was assumed. The financial structure, such as the degree of competition, the degree of finances marketization and credit funds allocation, played a decisive role for the degree of financial constraints faced by enterprises.

### 3.2. Object of the study

In this paper, the research sample space is 121 lighting production enterprises, of which the proportion of small and medium-sized enterprises accounts for 69 %. This represents a total of 83 small and medium-sized lighting production enterprises. The proportion of state-owned enterprises and non-state-owned enterprises which accounts for the total sample is basically balanced, and is 35 and 34 % respectively. This means that there are 42 state-owned enterprises and 41 non-state-owned enterprises. In the total sample, there are 38 large lighting enterprises which accounts for about 31 % of the total samples. Also, there are 15 large state-owned enterprises, representing a proportion of 12 %, and 23 large non-state enterprises, which accounts for a proportion of 19 %.

### 3.3. Acquisition of related data

The research data of this paper come from the survey of Chinese lighting manufacturers which was made by a research group from Tsinghua University, the Institute of Economics, Chinese Academy of Social Sciences and some American researchers. The data were collected in 2014, and the range of data is from 2012 to 2013.

### 3.4. Definitions of related variables

This paper measured the degree of financial constraints by examining the degree of difficulties with working capital and long-term investment funds. The evaluation of financial structure was measured in three aspects: the degree of competition, the degree of marketization and the degree of marketization of credit funds distribution. Specific definitions of variables are shown in Table 1.

### 3.5. Model establishment

Based on the two theoretical hypotheses about financial constraints mentioned earlier, this paper focused on the analysis of the impact of corporate factors and financial structure on corporate financial constraints. As the value of the degree of difficulties in the underflow of funds and long-term investment funds could only be 1, 2 or 3, these discrete but ordered data were further analysed by establishing a sequence of Probit regression models (Eqn 1). where $j$ stands for a lighting fixture manufacturing enterprise; $P_r$ is the probability; the corresponding degree of difficulty $i$ is equal to 1, 2 or 3; $k_{i-1}$ and $k_i$ are the critical values, and $u$ is the difference of the normal distribution. This formula gives the regression model of the enterprise $j$.

## 4. RESULT ANALYSIS AND DISCUSSION

### 4.1. Regression results for the entire sample

The regression results for the entire sample are shown in Tables 2 and 3. The results show that the higher the proportion of tangible assets, the higher the asset ability; also, the lower the difficulty of the

$$P_r\left[LTFC_j(STFC_j)=i\right]=P_r\left[\begin{array}{l} k_{i-1}<\beta_1\times \mathrm{Pr}ofita_j+\beta_2\times SBC_j\times \mathrm{Pr}ofita_j \\ +\beta_3\times Fainwestg_j+\beta_4\times Overdueloand_j \\ +\beta_5\times \mathrm{Tan}\,giblea_j+\beta_6\times Stockd_j \\ +\beta_7\times Bondd_j+\beta_8\times Corporatization_j \\ +\beta_9\times Central_j+\beta_{10}\times \mathrm{Pr}ovince_j+ \\ \beta_{11}\times City_j+\beta_{12}\times County_j+ \\ \beta_{13}\times No\,\mathrm{sup}_j+\beta_{14}\times Other\,\mathrm{sup}_j+ \\ \beta_{15}\times SOE_j+\beta_{16}\times SME_j+ \\ \beta_{17}\times FMI_j(FCI_j,CMI_j)+u_j\le k_i \end{array}\right], \quad (1)$$

**Table 1. Definitions of measurement indicators related variables**

| | |
|---|---|
| LTFC | Degree of difficulties with long-term investment funds: 1 is for it wasn't difficult, 2 is for it was difficult, 3 is for it was very difficult. The time of filling in the form was in 2014. |
| STFC | The difficulty with insufficient liquidity of funds: 1 is for it wasn't difficult, 2 is for it was difficult, 3 is for it was very difficult. The time of filling in the form was in 2014. |
| Profit | Average profit rate of enterprises assets from 2012 to 2013 = the average profit/average total assets of an enterprise. |
| SBC | Soft constraints on dummy variables were estimated: if the average profit from 2012 to 2013 was less than 0, then SBC=1; and if the average profit from 2012 to 2013 was more than 0, then SBC=0. |
| Fain vesting | Average growth rate of enterprises fixed assets investment from 2012 to 2013. |
| Overdue loaned | Dummy variable of the debt owed by the enterprise: if the company had outstanding debts due before 2013 (including in 2013), then the Overdue loaned = 1; otherwise, the Overdue loaned = 0. |
| Tangible | The average tangible assets ratio of enterprises from 2012 to 2013 = the average of the ratio of tangible assets/total assets. |
| Stocked | If the company issued shares before 2013 (including 2013), dummy variable of enterprise issuing stock = 1; otherwise, dummy variable of enterprise issuing stock = 0. |
| Bonded | The virtual variable of the stock issued: if the firm issued a bond before 2013 (including 2013), then the Stocked = 1; otherwise, the Stocked = 0. |
| Corporatization | The dummy variable of enterprise's system reform: if the enterprise before 2013 (including 2013) was in accordance with the companies restructuring law, then the Corporatization = 1, otherwise, the Corporatization = 0. |
| Central | Central management of the company's virtual variables: if the enterprise belonged to the central management, then the Central = 1; otherwise, the Central = 0. |
| Province | Provincial management enterprise virtual variables: if the enterprise belonged to the province's management, then the Province = 1; otherwise, the Province = 0. |
| City | Virtual variables of city management of enterprises: if the enterprise belonged to the city management, then the City = 1; otherwise, the City = 0. |
| County | Virtual variables of county management of the enterprise: if the enterprise belonged to the county's management, then the County = 1; otherwise, the County = 0. |
| Nosup | There were no competent virtual variables of the enterprise: if the enterprise didn't have a competent department, then the Nosup =1; otherwise, the Nosup = 0. |
| Othersup | The virtual variables when the competent department was another: if the competent authorities of the enterprise were in other circumstances, then the Othersup = 1; otherwise, the Othersup = 0. |
| SOE | Dummy variable of enterprise property right structure: if the enterprise was a state-owned enterprise, then SOE = 1; otherwise, the SOE = 0. |
| SME | Dummy variables of company size: if it was a small or medium-sized enterprise, then the SME=1; otherwise, the SME=0. |
| FMI | In 2013, the marketization of the financial sector included financial sector tensions and marketization of credit allocation. |
| FCI | In 2013, the competition objective of the financial industry was equal to the proportion of deposits absorbed by financial institutions in non-state-owned lighting production enterprises in all regions. |
| CMI | In 2013, the distribution of credit funds was equivalent to the proportion of short-term loans of the state-owned lighting manufacturers in the financial institutions of the enterprises in the region. |

**Table 2. Ordinal regression results for the entire sample LTFC**

| | LTFC | | | | | |
|---|---|---|---|---|---|---|
| | | **Z test** | | **Z test** | | **Z test** |
| Profit | 0.2316 | 0.32 | 0.2730 | 0.36 | 0.2034 | 0.27 |
| SBC Profit | -0.6784 | -0.44 | -0.6162 | -0.41 | -0.6940 | -0.46 |
| Fain vesting | -0.0017 | -0.04 | -0.0016 | -0.04 | 0.0029 | 0.07 |
| Overdue loaned | 0.0067 | 0.07 | 0.0103 | 0.10 | -0.0129 | -0.12 |
| Tangible | 0.0598 | 0.06 | 0.1396 | 0.12 | -0.0508 | -0.05 |
| Stocked | -0.1390 | -0.360 | -0.1367 | -0.30 | -0.1478 | -0.32 |
| Bonded | -0.2274 | -0.68 | -0.2139 | -0.64 | -0.2169 | -0.64 |
| Corporatization | 0.0115 | 0.12 | 0.0039 | 0.04 | 0.0122 | 0.12 |
| Central | Dropped | | Dropped | | Dropped | |
| Province | 0.3726 | 1.55 | 0.3521 | 1.51 | 0.3935 | 1.64 |
| City | -0.1840 | -0.95 | -0.1771 | -0.91 | -0.1512 | -0.77 |
| Country | -0.0929 | -0.30 | -0.0832 | -0.26 | -0.0777 | -0.25 |
| Nosup | -0.0356 | -0.12 | -0.0379 | -0.12 | -0.0015 | -0.00 |
| Othersoup | -0.2018 | -0.71 | -0.2034 | -0.72 | -0.1549 | -0.55 |
| SOE | 0.3129 | 1.77 | 0.3112 | 1.76 | 0.3498 | 1.98 |
| SME | 0.3666 | 2.99 | 0.3666 | 2.99 | 0.3678 | 3.00 |
| FMI | 0.0230 | 1.26 | | | | |
| FCI | | | 0.0250 | 1.49 | | |
| CMI | | | | | 0.0041 | 0.31 |
| Cut1 | 0.5177 | | 0.5960 | | 0.3852 | |
| Cut2 | 1.7788 | | 1.8566 | | 1.6444 | |
| Obs | 584 | | 584 | | 584 | |
| Pseudo R2 | 0.0314 | | 0.0319 | | 0.0301 | |

loan, the smaller the financial pressure – that is, the less the degree of financial constraints. What's more, the difficulties with issuing shares or bonds are positively related to the difficulty in the liquidity of the enterprises. This shows that the reform of the enterprise system has a clear negative correlation with the difficulties with working capital. The results show that the reform of the enterprise system is an effective measure to help the enterprise development. This is because it can not only strengthen the accumulation of internal funds – it can enhance the negotiation between enterprises and banks as well. The structure of property rights has a significant effect on both the difficulties with long-term investment funds and working capital. Additionally, the result also shows that the size of the enterprise plays a significant role in the difficulties with long-term investment funds and working capital. However, there is no obvious relationship between the degree of financial marketization and the degree of financial constraints.

### 4.2. Regression results for specific samples

The regression results for specific samples are shown in Tables 4 and 5 and Figs. 1–6. It can be seen from the results that the growth rate of fixed asset investments of large state-owned lighting

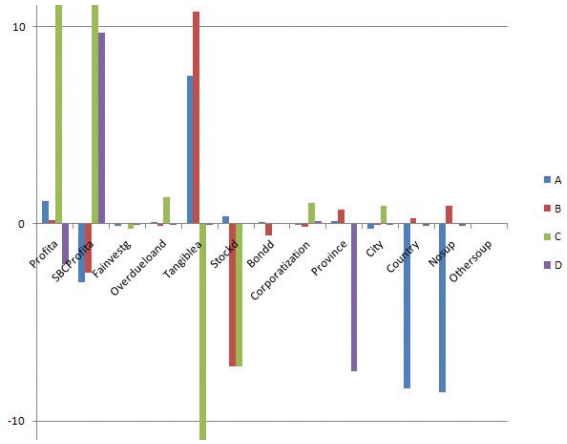


Fig.1. Regression results for various factors of specific samples LIFC

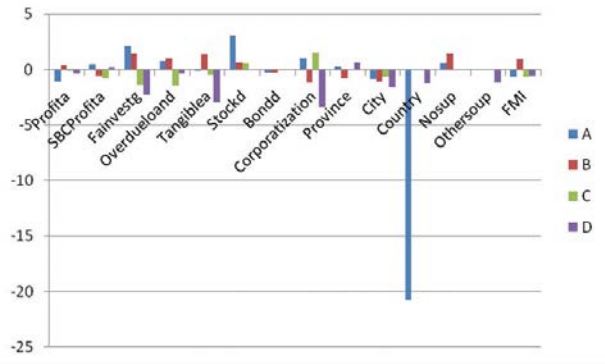


Fig.2. Regression analysis of the factors of specific samples, Z test for the LIFC

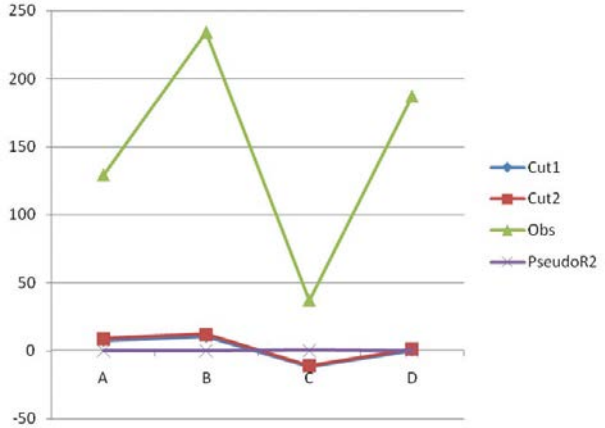


Fig.3. Analysis results for LIFC data

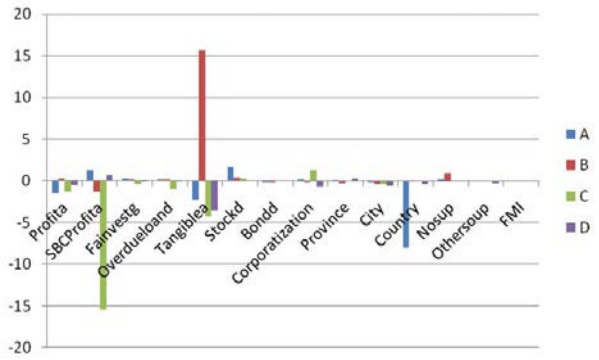


Fig. 4. Regression results for various factors of specific samples SIFC

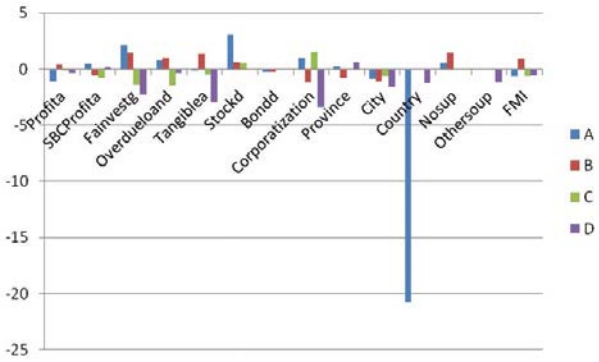


Fig. 5. The regression analysis of the factors of specific samples, Z test for the SIFC

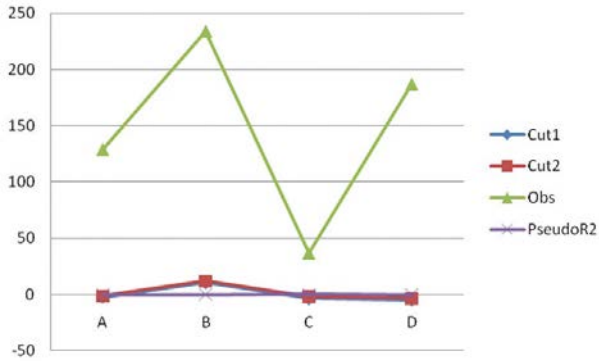


Fig. 6. Analysis results for the SIFC data

manufacturers is related to the degree of difficulties with the working capital. It is also realized that the difficulties with issuing stocks and bonds for large state-owned lighting manufacturers has a significant positive correlation with the difficulties with their working capital. Compared to the central management of enterprises, the role of the government in county management of enterprises is even more pronounced in terms of helping with the lack of liquidity and long-term investment funds. Also, long-term investment funds of large state-owned lighting manufacturers without competent departments are generally more adequate. Therefore, the theory of financial structure isn't valid for large state-owned lighting enterprises.

For small and medium-sized state-owned lighting manufacturers, the degree of difficulties with the issuance of stocks and bonds and the degree of difficulties with long-term investment funds show a significant negative correlation. Compared with large

**Table 3. Ordinal regression results for the entire sample STFC**

| | STFC | | | | | |
|---|---|---|---|---|---|---|
| | | **Z test** | | **Z test** | | **Z test** |
| Profit | -0.4047 | -0.66 | -0.4301 | -0.71 | -0.4699 | -0.78 |
| SBC Profit | -0.0096 | -0.02 | -0.0385 | -0.03 | -0.1092 | -0.07 |
| Fain vesting | -0.0371 | -0.83 | -0.0345 | -0.77 | -0.0418 | -0.95 |
| Overdue loaned | 0.0822 | 0.76 | 0.0699 | 0.65 | 0.0954 | 0.90 |
| Tangible | -2.7330 | -2.31 | -2.8127 | -2.38 | -2.8324 | -2.38 |
| Stocked | 1.1442 | 2.85 | 1.1432 | 2.91 | 1.1523 | 2.78 |
| Bonded | -0.1860 | -0.47 | -0.1792 | -0.45 | -0.2326 | -0.59 |
| Corporatization | -0.1926 | -1.84 | -0.1931 | -1.80 | -0.1781 | -1.70 |
| Central | Dropped | | Dropped | | Dropped | |
| Province | -0.1439 | -0.54 | -0.1295 | -0.49 | -0.1429 | -0.53 |
| City | -0.2811 | -1.38 | -0.2609 | -1.29 | -0.3284 | -1.61 |
| Country | -0.1822 | -0.64 | -0.1734 | -0.61 | -0.2161 | -0.75 |
| Nosup | 0.4950 | 1.60 | 0.5155 | 1.69 | 0.4700 | 1.53 |
| Othersoup | -0.0408 | -0.15 | -0.0069 | -0.03 | -0.0825 | -0.30 |
| SOE | 0.5512 | 3.44 | 0.5750 | 3.63 | 0.5211 | 3.29 |
| SME | 0.3555 | 2.90 | 0.3636 | 2.91 | 0.3617 | 2.88 |
| FMI | 0.0016 | 0.08 | | | | |
| FCI | | | -0.0100 | -0.62 | | |
| CMI | | | | | 0.0188 | 1.44 |
| Cut1 | -2.8103 | | -2.9006 | | -2.8774 | |
| Cut2 | -1.4444 | | -1.5333 | | -1.5088 | |
| Obs | 584 | | 584 | | 584 | |
| Pseudo R2 | 0.0395 | | 0.0398 | | 0.0411 | |

state-owned enterprises, the reform of joint-stocks of small and medium-sized enterprises can help to alleviate the pressure of financial constraints. However, the government plays less effective role in easing the long-term investment in the county management of enterprises. In summary, for small and medium-sized state-owned lighting enterprises, the data that can support the financial structure aren't found.

For large non-state-owned lighting manufacturers, the degree of long-term investment funds shows a clear positive correlation with the profitability of their assets, but it has a significant negative correlation with the proportion of assets. Similarly, for large non-state-owned lighting manufacturers, there are no data to support the financial structure theory.

For small and medium-sized non-state-owned lighting manufacturers, it is found that banks have a soft binding on loans of these enterprises. There is a significant negative correlation between the growth rate of fixed asset investment and the difficulties with liquidity of funds. As a result, it can be seen that the reform of the enterprise system has the phenomenon of restraining the difficulties with the enterprise liquidity. Compared with the central business sector, the county management enterprises are still able to use the government as a certain force to alleviate the lack of long-term investment funds.

**Table 4. Regression results for specific samples LIFC**

| | LTFC | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Large state-owned, A** | **Z test** | **Small and medium-sized state-owned, B** | **Z test** | **Large non-state, C** | **Z test** | **Small and medium-sized state-owned, D** | **Z test** |
| Profit | 1.1916 | 1.10 | 0.2026 | 0.20 | 16.3904 | 1.91 | -2.0184 | -1.05 |
| SBC Profit | -2.9394 | -1.18 | -2.4366 | -1.12 | 56.3435 | 0.60 | 9.7134 | 1.85 |
| Fain vesting | -0.0965 | -1.03 | 0.0685 | 0.67 | -0.2500 | -1.11 | 0.0137 | 0.23 |
| Overdue loaned | 0.1153 | 0.48 | -0.0990 | -0.56 | 1.3589 | 1.63 | 0.0327 | 0.17 |
| Tangible | 7.5104 | 0.46 | 10.7718 | 0.96 | -15.0184 | -1.81 | -0.0574 | -0.05 |
| Stocked | 0.4157 | 0.84 | -7.2078 | -12.72 | -7.2269 | -13.82 | Dropped | |
| Bonded | 0.0969 | 0.26 | -0.5532 | -1.06 | Dropped | | Dropped | |
| Corporatization | -0.0553 | -0.22 | -0.1482 | -0.91 | 1.0829 | 1.19 | 0.1774 | 0.85 |
| Province | 0.1781 | 0.49 | 0.7466 | 1.73 | Dropped | | -7.4363 | -13.51 |
| City | -0.2470 | -0.98 | 0.0171 | 0.05 | 0.9268 | 1.38 | -0.0555 | -0.15 |
| Country | -8.3377 | -21.77 | 0.2929 | 0.49 | Dropped | | -0.1001 | -0.29 |
| Nosup | -8.5079 | -2777 | 0.9555 | 0.49 | Dropped | | -0.1001 | -0.29 |
| Othersoup | Dropped | | Dropped | | Dropped | | -0.1103 | -0.37 |
| FMI | 0.0055 | 0.15 | 0.0321 | 1.25 | 0.0478 | 0.40 | 0.0209 | 0.58 |
| Cut1 | 7.5616 | | 10.5928 | | -12.0278 | | 0.1523 | |
| Cut2 | 8.9015 | | 12.0071 | | -11.1201 | | 1.3379 | |
| Obs | 129 | | 234 | | 37 | | 187 | |
| PseudoR2 | 0.0315 | | 0.0440 | | 0.2507 | | 0.018 | |

Consistent with the foregoing, the data that can support the financial structure of small and medium-sized non-state-owned lighting manufacturers are not found.

To sum up, the analysis of data in this paper was consistent with the theory that enterprise factors play an important role in the financial constraints of the enterprise. The relevant data supporting the consistency with the financial structure aren't found.

## 5. CONCLUSIONS

In this paper, 121 lighting manufacturers were taken as the research sample space. Through the establishment of a metrological regression model, the entire sample and large state-owned enterprises, small and medium-sized state-owned enterprises, large non-state-owned enterprises and small and medium-sized non-state-owned enterprises were analysed. The validation of the debate on the financial constraints of the two financial sectors in the corporate factor theory and the financial structure theory was realized. The conclusion is that the enterprise factor is the main factor that affects the financial constraint of the enterprise. The influence of the financial structure on the financial constraint isn't found in this research. Although the research of this paper has some limitations in the research sample and model establishment, it is believed that this work will inspire the government to help enterprises to alleviate the financial constraints, and

**Table 5. Regression results for specific samples SIFC**

| | STFC | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Large state-owned** | **Z test** | **Small and medium state-owned** | **Z test** | **Large non state-owned** | **Z test** | **Small and medium-sized non state-owned** | **Z test** |
| Profit | -1.4616 | -1.09 | 0.3097 | 0.36 | -1.3261 | -0.09 | -0.5229 | -0.33 |
| SBC Profit | 1.3018 | 0.45 | -1.3314 | -0.57 | -15.4299 | -0.79 | 0.6937 | 0.15 |
| Fain vesting | 0.2817 | 2.12 | 0.1683 | 1.44 | -0.4267 | -1.35 | -0.1285 | -2.31 |
| Overdue loaned | 0.1966 | 0.80 | 0.1771 | 1.01 | -0.9627 | -1.49 | -0.0751 | -0.38 |
| Tangible | -2.2442 | -0.14 | 15.6808 | 1.38 | -4.2164 | -0.49 | -3.5809 | -2.94 |
| Stocked | 1.6599 | 3.05 | 0.4035 | 0.61 | 0.3015 | 0.55 | Dropped | |
| Bonded | -0.1537 | -0.30 | -0.1674 | -0.26 | Dropped | | Dropped | |
| Corporatization | 0.2306 | 0.98 | -0.1946 | -1.19 | 1.2548 | 1.49 | -0.6978 | -3.36 |
| Province | 0.0834 | 0.22 | -0.3463 | -0.82 | Dropped | | 0.2636 | 0.62 |
| City | -0.2311 | -0.89 | -0.4024 | -1.11 | -0.3467 | -0.63 | -0.6223 | -1.64 |
| Country | -8.0438 | -20.79 | -0.0878 | -0.018 | Dropped | | -0.3666 | -1.22 |
| Nosup | 0.1513 | 0.53 | 0.9071 | 1.42 | Dropped | | Dropped | |
| Othersoup | Dropped | | Dropped | | Dropped | | -0.3345 | -1.17 |
| FMI | -0.0275 | -0.66 | 0.0251 | 0.91 | -0.0529 | -0.66 | -0.0192 | -0.59 |
| Cut1 | -2.3663 | | 10.5928 | | -3.7094 | | -4.8427 | |
| Cut2 | -1.3916 | | 12.0071 | | -1.7777 | | -3.4080 | |
| Obs | 129 | | 234 | | 37 | | 187 | |
| PseudoR2 | 0.0636 | | 0.0440 | | 0.1834 | | 0.0796 | |

it will play a practical role in assisting with enterprise's own factors. This could be done for different enterprises in order to develop different support programs, so that the role of the government can be maximized. The research data of this paper can provide some reference for future research on the influence of enterprise factors and financial structure on financial constraints.

## ACKNOWLEDGEMENT

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# INNOVATION MANAGEMENT OF LIGHTING ENTERPRISES BASED ON GRAY MANAGEMENT

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**ABSTRACT**

With society development and economic globalization, many entrepreneurs are developing their enterprises with gray management being the core of the enterprise. Lighting is essential for people's lives, and as lighting enterprises are mature and stable traditional enterprises, it is also important for them to adapt to the innovation management of the era. Therefore, based on the gray management, this paper expounded the theory of gray management and enterprise innovation management; the evaluation model of the maturity of lighting enterprise innovation management capability was established. A questionnaire survey was also conducted to verify the maturity of the innovation management capability of enterprises, so as to verify the level of innovation management abilities further. It appears that most of the innovative managements of lighting enterprises still have room for improvement at this stage.

**Keywords:** gray management, innovation, lighting enterprise, model

## 1. INTRODUCTION

Lighting is essential for people's life. With the development of human society, torches and lamps were used consecutively, and then the British invented the gas lamp more than 100 years ago, making a step forward in lighting [1]. At the end of the nineteenth century, electric light was invented by Edison, which rewrites the history of lighting [2] and makes humans step into the era of electric lighting; there were numerous changes in lighting tools, such as torches, oil lamps, fluorescent lamps, even modern energy-saving lamps, etc. The historical development of lighting also witnesses the history of human development. Lighting industry, as a traditional industry, is in a relatively mature and stable period of development. Internationally renowned lighting companies such as Philips, Panasonic, Cooper and others as well as their overturn account for 50 % of the world market. The survival and development of China's lighting enterprises in the fierce market require enterprises to work out their own development strategies and management implementations to meet new challenges and innovations. The soul of a country's or a nation's development is innovation [3]. This is the most important element of the national and regional economic development, and in the face of increasingly fierce market competition, the state and enterprises are advocating, encouraging and supporting innovations. At present, China is still at the stage of rapid economic development, so it needs more creative and innovative talents, and it should form its own needs or introduce innovative approaches and innovative management models, so as to improve the overall innovation ability and level [4]. Lighting enterprises are relatively mature and stable traditional enterprises. In order to obtain long-term competitive advantages, it is necessary to actively carry out independent researches and developments, technological innovations and other related activities [5]. With the pace of economic globalization, the world has already entered the stage of free competitions, so in the current environment of survival of the

fittest, the economic competitions between countries and enterprises are competitions of talents, science and technology, and the competition of innovation abilities is one of the most important aspects [6]. Innovation can guide a new trend of the development, and it can achieve the green development of the economy, which is also the main driving force to make a breakthrough in the slow overall growth of the global economy [7]. Compared with the developed countries, there is still a certain gap between the innovation abilities of lighting enterprises in China and developed countries [8]. On the whole, most of lighting enterprises in China rely mainly on external introduction of technologies or on imitation innovations, which means strong technical dependences [9]. The inadequate investment in innovations hardly can support the needs of innovations; the personnel training mechanism of enterprises is not perfect – the internal personnel training is low-efficient while external talents can't be introduced in time; the internal management knowledge is not perfect, and the information exchange is not smooth, resulting in irrational allocations of resources; the lack of advanced methods of innovations leads to unsatisfactory innovation efficiencies and results. In the face of many factors that affect the enterprise and the national innovation ability, enterprises and international communities are also exploring new models for innovation and development, and increasing their attention to innovations and investments in them [10].

Human life is closely related to the development of science and technology; enterprises, as the main component of economic life, are inseparable from scientific and technological innovations. There is a market demand for enterprises development, and preparations are to be made to combine the competition with technological innovations and to adapt to imperatives. Lighting enterprises are traditional enterprises that are essential for human life, and their level of scientific and technological development can represent the level of the technological development of a country to a certain extent; innovation management ability is also a manifestation of competitions of the national soft power, so it is an important index in the Internet economic environment. Since the reform and opening up, China's economy has been increasing at a high rate every year. This increase is due to the country's high investments, including investments in a large number of fixed assets and the development of large national trades, which is a more extensive way of development to some extent. With the development of innovative national strategies, China's economic development has begun to pay close attention to scientific and technological innovations, green industrial layouts, etc. The core of these changes is related to the innovation ability, and it is particularly important in both business management and technical aspects. Under the influence of relevant policies, many excellent entrepreneurs put forward the concept of gray management, so it is of a great theoretical significance and practical value to study the innovation management ability of the lighting enterprises based on the gray management.

## 2. STATE OF THE ART

Ren Zhengfei, the president of HUAWEI, highly praises the gray management in a series of management reforms. Here, the gray level is to enable the leaders to grasp clear direction and moderate rhythm [11]. The direction of the enterprise will accurately change with time and space, and it often becomes unclear. At this stage, the leaders need to grasp the gray level in the management, so that various factors affecting the direction of development in a period of time will maintain the harmony. The process of maintaining harmony is called compromise. The result is the gray level. It can be seen that the gray management means the understanding of the art of compromise, tolerance, open mind, etc, which enables the enterprise to go further steadily along the right way. It is manifested not only in compromise, but also in acting according to the laws of nature and seeking of truth from facts.

However, in the internal management of enterprise innovation, different researchers have defined the concept from their own points of view, and there is no uniform standard definition [12]. Some scholars believe that the enterprise innovation management is an effective management method, which can simplify the list of enterprise innovation activities, and provide the most clear objective management for the enterprise; but this way has not been introduced into most enterprises. Some other scholars believe that enterprise innovation management is the process of obtaining innovations to make the full use of various enterprise resources, and it can also be said that this is a new management idea that is put forward to achieve the desired purposes, and this process is a non-continuous one. According

to the relevant literature, the innovation management is internal and external, enabling the enterprise to adapt to the changing development. Through the use of new management models, methods, and so on, it can create new, scientific and effective management methods to attain reasonable internal and external resources, so as to realise economic interests, management efficiency and innovations of the enterprise, and as a result to maximize the benefits of the systems and activities of dynamic management. Innovation management is the key to improving the innovation ability of enterprises, and scholars at home and abroad proposed different analyses on innovation management abilities. With the continuous development of the research, the innovation of management begins to focus on the process and the management of main activities. From the perspective of technological innovation researches, some scholars believe that the process of technological industrialization, commercialization and socialization is a technological innovation, and this process needs to be completed in principles, so as to change the potential productivity into the real productivity. Some scholars also think that in the process of innovation, innovations come from the design and development of products. From the perspective of technological innovation, it can be seen that too much attention has been paid to technical elements of innovations, ignoring the internal structure of innovation elements and the influence of relationships between them. From the perspective of institutional innovation, some scholars think that the enterprise's property right system is the core for the entrepreneurs to form their innovative behaviours, which is also the driving force to promote enterprise innovation, etc. At present, the research on institutional innovation is mainly focused on innovations in property right system, and on the composition and realisation of enterprise system innovations under different ownership forms. Institutional innovation for enterprises development is still relatively less explored. Starting from the perspective of system innovation, some scholars believe that the innovation system is composed of material and human resources, innovation environments and organization systems. It can be seen that the research on innovation management system is based on the dynamic environment, which highlights the impact of the interaction among the subsystems within the management system of innovation performances; it is still confined to interactions between innovation factors. From the core point of view, some scholars pointed out that there is a kind of hierarchical relationship in the innovation management activities of enterprises so as to promote innovation activities layer by layer.

## 3. METHODOLOGY

Based on the research on innovation management of lighting enterprises on the basis of gray management, an evaluation model of innovation management capability maturity was constructed, so as to evaluate and put forward some suggestions on the innovation management of lighting enterprises.

### 3.1. Construction of innovation management maturity model

The construction of innovation management maturity model should be based on gray management, and from the perspective of innovation management theories and through the comprehensive analysis of relevant literature, it makes the guiding ideology of innovation management maturities clear. The focus of innovation management is on the balance between innovations and executions, so as to carry out innovation activities, to form enterprises' innovation management abilities, and to improve the efficiency of innovation outputs of enterprises. In this model, it is necessary to combine the concept of gray management, innovative organization models management and project operation management, so as to ensure the rationality of innovation activities and the vitality of the durability. The evaluation model of innovation management maturity is a kind of a tool for identification of the enterprise innovation managements system, and it can help enterprises to analyse their own advantages and disadvantages in innovation activities, so as to make up for their own shortcomings and realise their own advantages.

### 3.2. Definition and classification of maturity levels

Management and technology are two important factors in the innovation management capability maturity model. The level of management will affect the overall situation, and the technology will affect the local part, so the innovation management capability model is an important standard for maturity of management innovations and tech-

**Table 1. Summary of innovation management capability maturity levels and characteristics**

| Maturity level | Management level | Characteristic |
|---|---|---|
| Initial stage | Disordered management | Management begins to recognize the importance of innovation management capabilities |
| Defined level | Initial management | According to the plan to train for innovative working methods, application process of learning innovation management has a certain degree of controllability and balance |
| Managed level | Standardized management | It means having a complete innovation management mechanism, and innovation and management capabilities can be upgraded effectively and orderly |
| Optimal coordination level | Label management | The use of quantitative indicators to measure the performance of innovation managements, and innovation process has a high degree of cooperation and continuous improvement |

nology development evaluation. The most important index of this model is the balance between innovation and execution. In this work, based on the capability maturity model combined with the analysis of innovation management elements, the innovation management capability is divided into four stages: the initial level, the defined level, the management level, and the optimized collaborative level. Its management levels and characteristics are shown in Table 1. The innovation management capability maturity model will focus on the evaluation of each capability maturity level, and through a clear evaluation of the level, enterprises will find ways to make improvements in the future according to the actual application.

### 3.3. Key areas and practices

The innovation management capability maturity model is similar to the CMM model (Capability Maturity Model). Each maturity level contains a number of key process areas and practices. In this study, key process areas and practices were identified through the comprehensive analysis of the relevant literature, the success stories of innovation managements and the experience of innovation management experts. Key process areas and practices that are corresponding to the four levels are shown in Table 2.

### 3.4. Setting the evaluation index system

Factor selection

The evaluation index system of innovation management capability maturity of enterprises should be taken into consideration in many aspects, perspectives and levels, and the principles of operation and information should be followed. In this work, based on the relevant literature, the evaluation index of innovation management abilities, the comprehensive analysis and four abilities were taken as the evaluation criteria, and the corresponding sub-criteria evaluation was developed. Detailed evaluation model of the innovation management capability maturity is shown in Fig. 1.

Weight assignment

In this paper, the analytic hierarchy process and fuzzy comprehensive evaluation were used. The combination of these two indexes can be divided into hierarchical structures, and through the evaluation index weight and the hierarchical fuzzy comprehensive judgment, the comprehensive evaluation results can be obtained finally. Here we used the expert scoring method to calculate the index weight: $U$ = (0.2566, 0.3585, 0.1589, 0.2257), and the weights of sub-criteria layers are obtained by the same method:

$U1$ = (0.3462, 0.3462, 0.3076),
$U2$ = (0.3077, 0.3269, 03654),
$U3$ = (0.3393, 0.3036, 03571),
$U4$ = (0.3822, 0.3125, 0.3053).

### 3.5. Selection of the evaluation method

The comprehensive evaluation index system of enterprise innovation management capability maturity is the structure with two layers and three levels. Most of these evaluation indexes are fuzzy; according to FUZZY theory, the first-level evaluation is to judge the main criterion by the sub-cri-

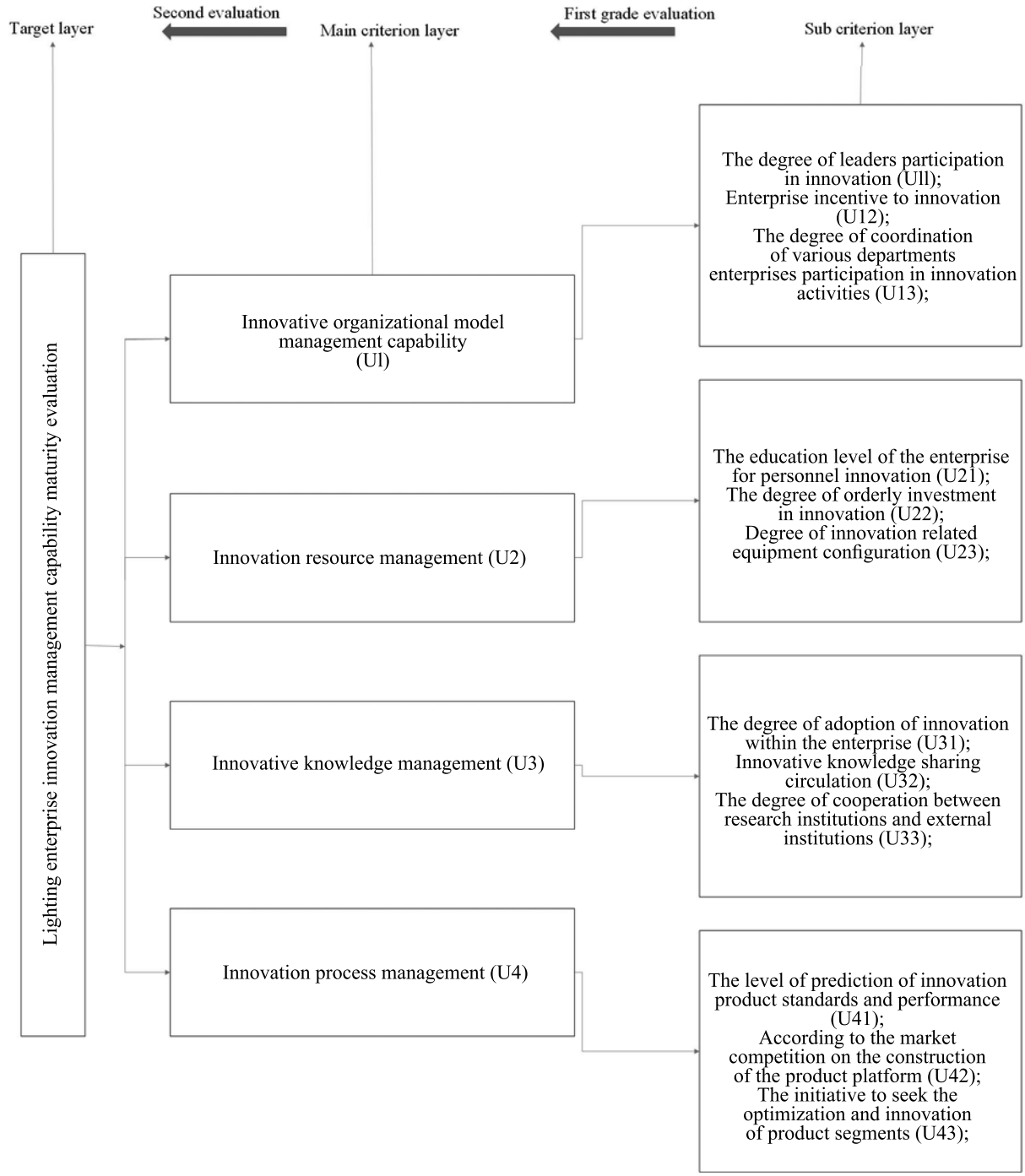


Fig 1. A comprehensive evaluation index system of innovation management capability maturity

terion layer, and the second-level evaluation is the evaluation of the main criterion, so that the fuzzy comprehensive evaluation model with two layers and three levels is formed.

Specific steps are as follows: firstly, we set up the ability of innovation management capability maturity evaluations $U = \{U1, U2, \ldots, Un\}$, and then experts assign scoring weights to obtain the average weight. Secondly, we use the level of evaluations: the evaluation of each sub-element is set to make a comprehensive evaluation.

Evaluation set is as follows:

$$V = \left\{ \begin{matrix} \textit{Initial level}, \textit{defined level}, \textit{managed level}, \\ \textit{optimized collaboration level} \end{matrix} \right\}$$

Index weight set: we use the scoring weights given by experts to obtain the average weight. Then we get the average, and determine the final

**Table 2. Key areas and practices of innovation management capability maturity levels of lighting enterprises**

| Maturity level | Critical domain (KPA) | Critical practice (KP) |
|---|---|---|
| Initial stage | Guiding mechanism | Initiate and promote innovation management and its implementation results |
| Defined level | External cooperation and resource input management system | Government and university setting up a cooperation centre to achieve a combination of researches, developments strategies, funds, equipment and others to support innovation |
| Managed level | Innovation organization structure and innovation management operation mechanism | Setting up a professional team of innovation management, and clearing the key links and processes of innovation management |
| Optimal coordination level | Quantitative management and assessment | Use of quantitative indicators to measure the abilities of innovation management, so as to improve the efficiency of innovations |

weight of each evaluation index. It is shown as $Ui = (ai1, ai2, .....aij)$.

Fuzzy evaluation matrix: the evaluation factor set of lighting enterprise $Ui$ for the evaluation set $V$ is a fuzzy mapping, enabling to generate the fuzzy evaluation matrix $Ri$:

$$Ri = \{dijk / d\}, \tag{1}$$

where $dijk$ is the $ij$ evaluating indicator in evaluation subset $Ui$, and it is the $k$ evaluation in a number of responds, and $d$ is the total number of participants in the evaluation. This part of the data is derived from each of the evaluations of the questionnaire survey of lighting enterprises.

According to FUZZY theory, we use the fuzzy matrix synthesis to obtain the comprehensive evaluation $Mi$ vector:

$$Mi = Ui * Ri = (bi1, bi2, ....bin). \tag{2}$$

Thirdly, we carry out the second-level evaluation: each sub-element set $Ui$ is a factor, and $Mi$ is the single factor evaluation, so we obtain that the evaluation set $V$ of evaluation factor set $U$ of lighting enterprises is a fuzzy mapping. In set $U = \{U1, U2, ....Us\}$, each $Ui$ is a part of $U$, and the weights can be assigned in accordance with their importance $R = \{M1, M2, .....Ms\}$.

So the second-level comprehensive evaluation is:

$$M = U * R = (b1, b2, .....bn). \tag{3}$$

The evaluation results are normalized according to the maximum membership principle:

$$M = \max(b1, b2, .....bn). \tag{4}$$

Then we obtain that the comprehensive evaluation of FUZZY is $Vk$.

## 4. RESULTS ANALYSIS AND DISCUSSION

In order to verify the evaluation model of the innovation management capability maturity of lighting enterprises, effective data for 100 lighting enterprises were collected through questionnaires, and then according to the method described in the third part, the level of innovation management capability maturity was obtained. Finally, the corresponding analysis of the distribution of innovation management capability maturity of these 100 lighting enterprises was made.

### 4.1. Evaluation of maturity level of enterprise "*B*"

Here we introduced the evaluation process of the innovation management capability maturity of a single lighting enterprise. The evaluation results were obtained, and then the method was used for the evaluation of all other lighting enterprises.

(1) According to the calculation of expert weights of the four sub-abilities and the corresponding evaluation indexes, the following evaluation weight vectors were obtained:

**Table 3. Basic statistics of 100 surveyed lighting enterprises**

| Surveyed companies profiles | | Number of enterprises | Percentage | Cumulative percentage |
|---|---|---|---|---|
| Enterprise nature | State-owned enterprise | 24 | 24 % | 24 % |
| | Private enterprise | 32 | 32 % | 56 % |
| | Wholly foreign owned enterprise | 12 | 12 % | 78 % |
| | Joint-stock enterprise | 32 | 32 % | 100 % |

$$U = (0.2566, 0.3585, 0.1592, 0.2257)$$
$$U1 = (0.3462, 0.3462, 0.3076)$$
$$U2 = (0.3077, 0.3269, 0.3654)$$
$$U3 = (0.3393, 0.3036, 0.3571)$$
$$U4 = (0.3822, 0.3125, 0.3053)$$

(2) The evaluation set is:

$$\mathrm{V} = \left\{ \begin{matrix} \textit{Initial level}, \textit{defined level}, \textit{managed level}, \\ \textit{optimized collaboration level} \end{matrix} \right\}$$

(3) Based on the analysis of the 10 pieces of data for the lighting enterprise "*B*", the results are as follows: the fuzzy evaluation matrix was obtained and a comprehensive evaluation was carried out:

$$R_1 = \begin{pmatrix} 0.2,0.4,0.3,0.1 \\ 0.2,0.4,0.3,0.1 \\ 0.2,0.5,0.3,0 \end{pmatrix} \quad (5)$$

$$R_2 = \begin{pmatrix} 0.1,0.7,0.2,0 \\ 0.1,0.6,0.3,0 \\ 0,0.6,0.4,0 \end{pmatrix} \quad (6)$$

$$R_3 = \begin{pmatrix} 0.1,0.5,0.3,0.1 \\ 0.1,0.6,0.3,0 \\ 0,0.6,0.3,0.1 \end{pmatrix} \quad (7)$$

$$R_4 = \begin{pmatrix} 0,0.7,0.3,0 \\ 0.1,0.8,0.1,0 \\ 0.2,0.5,0.3,0 \end{pmatrix} \quad (8)$$

$$M_1 = U_1 * R_1 = (0.2,0.4308,0.3,0.0692). \quad (9)$$

$$M_2 = U_2 * R_2 = (0.0635,0.6308,0.3058,0). \quad (10)$$

$$M_3 = U_3 * R_3 = (0.0643,0.5661,0.3,0.0696). \quad (11)$$

$$M_4 = U_4 * R_4 = (0.0923,0.6702,0.2375,0). \quad (12)$$

(4) We make a comprehensive evaluation of the sample enterprise, and draw the conclusion.

$$R = \begin{pmatrix} 0.2,0.4308,0.3,0.0692 \\ 0.0635,0.6308,0.3058,0 \\ 0.0643,0.5661,0.3,0.0696 \\ 0.0923,0.6702,0.2375,0 \end{pmatrix}. \quad (13)$$

$$M = U * R = (0.1052,0.5781,0.2880,0.0288). \quad (14)$$

After normalization, according to the principle of maximum membership degree, we have:

$$M = \max(0.1054,0.5780,0.2880,0.0286) = \\ = 0.578. \quad (15)$$

Therefore, the second member in the evaluation results of the evaluation set V is the largest. According to the principle of the maximum degree of membership, the innovation management capability maturity of lighting enterprise "*B*" is defined.

According to the methods above, the distribution of the maturity level of the sample enterprise is evaluated, and then the innovation management capability maturity is evaluated for each of the investigated lighting enterprises. This paper does not list the evaluation process for other lighting enterprises. In it the statistical analysis of the sample enterprises and the use of SPSS19.0 for the distribution of the maturity of other lighting enterprises were obtained. The software interface is shown in Fig. 2.

### 4.2. Descriptive statistical analysis of surveyed enterprises

Basic statistics of lighting enterprises are shown in Table 3.

**Table 4. Maturity distribution of enterprises with different characteristics**

| | The initial level | The defined level | The managed level | The optimal coordination level |
|---|---|---|---|---|
| State-owned enterprise | 3 | 14 | 7 | 0 |
| Private enterprise | 5 | 15 | 9 | 3 |
| Wholly foreign owned enterprise | 0 | 3 | 6 | 3 |
| Joint-stock enterprise | 3 | 16 | 8 | 5 |

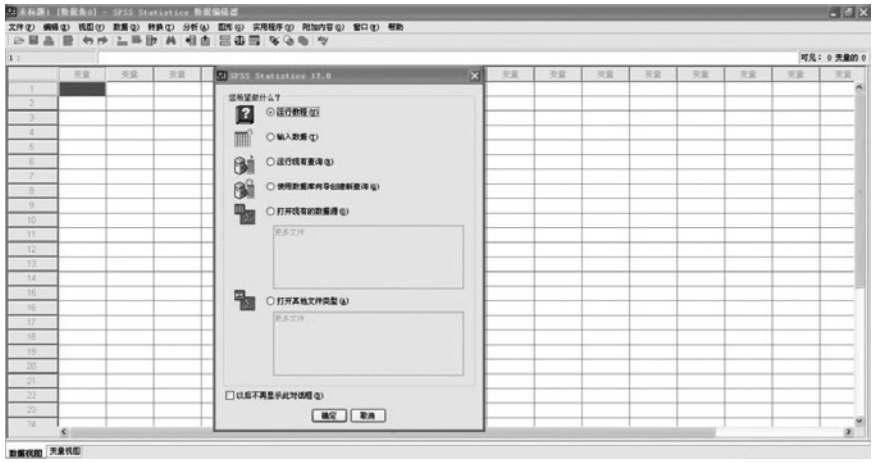

Fig 2. Interface of SPSS19.0 (Chinese version)

It can be seen from the table that proportions of private enterprises and joint-stock enterprises in the investigated lighting enterprises are higher.

### 4.3. The distribution of capability maturity of the surveyed enterprises

The results of the assessment of the capability maturity of the 100 enterprises under investigation are summarized in Table 4.

From Table 4, it can be seen that most of the innovation management capability maturities of foreign-owned lighting enterprises belong to the management level, and other lighting enterprises are already at the defined level. It shows that the innovation management ability of lighting enterprises is still at the middle level, and the innovation management has a lot of room for improvement.

## 5. CONCLUSIONS

With the development of human beings, lighting went through oil lamps, energy-saving lamps and other development stages, and it always has been an essential part of human life. Its development also witnesses the development of human history, and with the development of society and economic globalization, innovation is the soul of the development and progress of nations and enterprises. Many entrepreneurs need to adapt to the gray management and regard it as the core concept of the enterprise development, so that they can develop their enterprises better. Being mature and stable, traditional lighting enterprises also need to innovate to protect their development. Based on the gray management, the theory of gray management and enterprise innovation management was expounded in this work, and the evaluation model of the maturity of the innovation management capability of lighting enterprises was established. A questionnaire survey and the SPSS19.0 data analysis were used to verify the maturity of the innovation management capability of enterprises, so as to verify the level of innovation management abilities further. It shows that most of the innovative managements of lighting enterprises still have room for improvement.

The related theory and data of the research model have some limitations. But the authors made a preliminary discussion on the innovation management of lighting enterprises based on gray manage-

ment, and hope that researchers will be able to conduct further researches in the future.

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# OPTIMIZATION OF MULTI-OBJECTIVE REVERSE LOGISTICS NETWORK FOR LED LIGHTING PRODUCTS

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## ABSTRACT

A multi-objective reverse logistics network model was established under fuzzy environment. This model which depicted uncertainty in the network by a triangle fuzzy number is to minimize the total cost and maximize recycling in the supply chain. The multi-objective model under fuzzy environment was solved by the primary objective method and was proven feasible through a numerical example. This study could be a reference for lightemitting diode lights manufacturing enterprises in establishing recycling and re-manufacturing sites, and facilitate a reasonable network flow.

**Keywords:** LED lights, multi-objective, reverse logistics network

## 1. INTRODUCTION

The lightemitting diode (LED) industry in China is developing rapidly accompanied by the technological progress and the government support. The industry scale is quickly increasing annually. In 2014, the LED lighting output in China reached RMB350.7 billion, and the export volume exceeded $10.85 billion. China ranked first in the production and output of LED lights. The technological progress and upgrade of LED lights with their large-scale use result in considerable wastes. The latest research report from the University of California highlighted that, although LEDs are more environment-friendly than traditional lamps, they contain abundant aluminium, nickel, lead and arsenic, which are harmful to the environment and human health. Therefore, waste LEDs should be processed properly [1]. Meanwhile, LED lights consist of batteries, wires, circuit boards, glass, plastic cement and aluminium, and thus have certain resource potentials. Effective and scientific treatment can not only eliminate pollutions but also provide raw materials for national production, leading to environmental and economic benefits [2]. Therefore, it is highly imperative for enterprises to execute an effective management of the reverse logistics of LED lights. This is conducive to economic benefits, environmental benefits as well as resource conservation.

## 2. STATE OF THE ART

Compared with the conventional landfilling of municipal solid waste, reverse logistics has been attracting increasing attention with its significant contributions to sustainable development and circular economy [3]. The reverse logistics network design being an important research content of reverse logistics, has even attracted significant attention from Chinese and foreign scholars. Several experts emphasized the reverse logistics network for cost minimization or profit maximization to increase the efficiency of reverse logistics enterprises. Zarei et al. studied a reverse logistics network design for waste vehicles remanufacturing under the extended producer responsibility [4]. They considered distributing new vehicles and recycling of waste vehicles collectively, and established a network design model with cost minimization (including con-

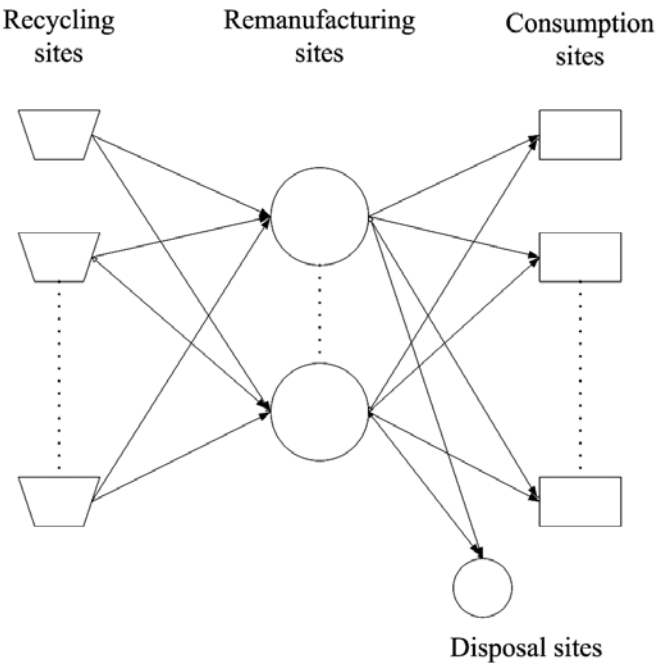


Fig. 1. Conceptual model of the reverse logistics network for LED lights

struction and related transportation costs) under the premise that the distributor of new vehicles is also responsible for the recycling of waste ones. Finally, they designed a genetic algorithm to solve the model. Ma et al. designed a reverse logistics network for the limited recycling of single products and established a corresponding mixed integral linear planning (MILP) model [5]. They solved the MILP model using the Benders decomposition algorithm. Then, on the basis of studies on economic benefits of the reverse logistics network, scholars further focused on environmental protection, resource conservation and service level, and established a multi-objective model. Based on the comprehensive consideration of network and environmental benefits, Rachaniotis et al. established a dynamic programming model of a single-period multi-objective reverse logistics network for waste computers [6]. Wang et al. studied a reverse logistics network layout for remanufacturing at transnational enterprises and considered the dual objectives of the logistics network, namely, maximum running income and logistics performance [7].

The abovementioned studies were based on known quantity, time, and quality of recycling products. However, product quantity, recycling rate and time are uncertain in the practical reverse logistics. For enhanced solutions of practical problems, scholars further focused on uncertainty factors and established uncertain random models and unique fuzzy programming models. Pishvaee et al. established a random model under uncertain conditions and solved it by the scenario-based random method [8]. Chen et al. established a multi-period and multi-objective model of a reverse logistics network for waste household appliances, aiming to maximize the profit of recycling enterprises and minimize the inefficiency of recycling centres, and considered the uncertainties of recycling quantity, quality and customer demands [9]. Chinese scholars studied the optimal design of the reverse logistics network under fuzzy environment to optimize a reverse logistics network model that contains subjective and uncertain factors. Qin and Ji established an optimal logistics network model for product recycling under fuzzy environment and proposed a mixed intelligent algorithm that combines fuzzy simulation and genetic algorithm to solve this model [10]. Gao et al. established an optimal reverse logistics network model that involves fuzzy parameters, and verified its validity and feasibility through examples [11].

In summary, although there are abundant studies on the reverse logistics network, only a few focused on the multi-objective reverse logistics network model for waste LED lights and involved several fuzzy variables. Therefore, based on a comprehensive consideration of economic and environmental benefits of recycling waste LED lights, a multi-objective reverse logistics network model for waste LED lights under fuzzy environment was established

in this study. This model aims to minimize the total cost and maximize the recycling rate, describes the recycling uncertainties in the reverse logistics network using the triangle fuzzy number, and solves them through the primary objective method. Finally, the established model was proven feasible and valid through examples. This model recommends varying quantities and locations of recycling and remanufacturing sites, and price subsidies are given fixed confidence coefficients and different recycling rates.

## 3. MODELLING

### 3.1. Problem description and model hypotheses

Selection of original LED manufacturers for reprocessing is favourable, because producing and reprocessing of waste LED lights require professional knowledge. In recent years, with a strong support of related national policies, several LED lights manufacturing enterprises have begun to construct self-running remanufacturing reverse logistics networks. In this study, a self-running three-level reverse logistics network for waste LED lights remanufacturing was constructed. First, the recycling sites transport recovered LED parts to the remanufacturing sites. Then the remanufacturing sites are responsible for packaging, transporting, testing, decomposing, storing, and processing the LED parts. At last, the reproduced products are delivered to consumption sites. The conceptual model is illustrated in Fig. 1.

For the convenience of modelling, several hypotheses were formed in this study:

(1) The recycling quantity of the recycle points is a fuzzy number.

(2) The alternative locations and quantities of recycling and remanufacturing sites are known.

(3) The recycling site should not exceed the maximum storage capacity, and the remanufacturing site should not surpass the maximum remanufacturing capacity.

(4) Because of the cost of transporting waste products to recycling in regions and the costs of disposing and recycling them completely in burning, this procedure is ignored in regions.

(5) The material consumption during the remanufacturing process is ignored, and the average remanufacturing rate of recycling products is known.

(6) The recycling site will provide certain price subsidies to increase the recycling rate.

### 3.2. Establishment of the model

(1) Symbols

$r$ is the $r$-th recycling site, $r \in \{1,2,...,R\}$;

$p$ is the $p$-th remanufacturing site, $p \in \{1,2,...,P\}$;

$c$ is the $c$-th consumption site, $c \in \{1,2,...,C\}$.

(2) Parameters

$x_{rp}$ is the quantity of products delivered from $r$ to $p$;

$y_{pc}$ is the quantity of products delivered from $p$ to $c$;

$C_{rp}$ is transportation cost of a unit product from $r$ to $p$;

$C_{pc}$ is the transportation cost of a unit product from $p$ to $c$;

$f_r$ is the construction cost of the alternative recycling site $r$;

$f_p$ is the construction cost of the alternative remanufacturing site $p$;

$OC_r$ is the unit processing cost of recycled products at $r$;

$OC_p$ is the unit processing cost of recycled products at $p$;

max $D_r$ is the maximum recycling capacity of $r$;

max $R_p$ is the maximum processing capacity of $p$;

min $Z$ is the minimum total cost of the reverse logistic network;

max $E_r$ is the maximum total recycling rate of the recycling site;

$\tilde{A}_r$ is the recycling quantity of waste products at $r$, which is a fuzzy number;

$\mu_r$ is the product recycling rate of $r$;

$S$ is the price subsidy for unit product recycling;

$\alpha$ is the average remanufacturing rate of recycled products.

(3) Decision variables

$X_r = 1$ means the recycling site is constructed at $r$, and $X_r = 0$ means not constructed.

$Y_P = 1$ means the remanufacturing site is constructed at $p$, and $Y_P = 0$ means not constructed.

$S_r = 1$ means that price subsidy is provided to recycled products at $r$, and $S_r = 0$ means not provided.

(4) Mathematical model

According to the description of parameters above, the following linear programming model was constructed:

$$\min Z = \sum_{r=1}^{R}\sum_{p=1}^{P}\left(C_{rp} + OC_r\right)x_{rp} + \\ + \sum_{p=1}^{P}\sum_{c=1}^{C}\left(C_{pc} + OC_p\right)y_{pc} + \sum_{r=1}^{R} f_r \cdot X_r + \\ + \sum_{p=1}^{P} f_p \cdot Y_p + \sum_{r=1}^{R}\sum_{p=1}^{P} x_{rp} \cdot s \cdot S_r. \quad (1)$$

$$\max E_r = \frac{\sum_{r=1}^{R} \tilde{A}_r \cdot \mu_r}{\sum_{r=1}^{R} \tilde{A}_r}. \quad (2)$$

$$\sum_{p=1}^{P} x_{rp} = \tilde{A}_r \cdot \mu_r. \quad (3)$$

$$\sum_{c=1}^{C} y_{pc} = \alpha \sum_{r=1}^{R} x_{rp}. \quad (4)$$

$$\sum_{p=1}^{P} x_{rp} \le \max D_r \cdot X_r. \quad (5)$$

$$\sum_{c=1}^{C} y_{pc} \le \max \mathrm{R_p} \cdot Y_p. \quad (6)$$

$$x_{rp} \ge 0. \quad (7)$$

$$y_{pc} \ge 0. \quad (8)$$

$$X_r = 0,1. \quad (9)$$

$$Y_p = 0,1 \quad (10)$$

$$S_r = 0,1. \quad (11)$$

Objective function equation (1) considers the cost minimization of the reverse logistics network for recycling of waste LED lights, including the minimum sum of construction costs for recycling and remanufacturing sites, running cost, transportation cost, and price subsidies, as the objective. Objective function equation (2) considers the maximum total recycling rate of the recycling sites as the objective. Meanwhile, constraint equation (3) is the recycling quantity of waste LED lights at different recycling points. Constraint equation (4) is the logistic equilibrium constraint. Constraint equation (5) controls the recycling capacity at different recycling sites within the maximum recycling capacity. Constraint equation (6) is the maximum capacity of remanufacturing centres in terms of processing waste LED products. Constraint equations (7) and (8) assert that the recycling and processing quantities are non-negative. Constraint equations (9)-(11) assert that $X_r$, $Y_P$, and $S_r$ are all 0, 1 variables.

### 3.3. Solution

Enterprises do not only focus on economic benefits but also focus on environmental benefits. The above model has two objectives, and thus it is a multi-objective model. To simplify the solution, the above model is solved by the primary objective method, i.e., using cost minimization as the primary objective. The other objective (recycling maximization) is used as a constraint. Thus, a multi-objective model is converted into a single-objective model [12].

Given that fuzzy numbers exist in constraint equations, the triangle fuzzy number (possible minimum, possible maximum, and parameters) is used. $\tilde{A}_r$ ($\tilde{A}_r = \left(A_r - \varepsilon_r, A_r, A_r + \delta_r\right)$) is a triangle fuzzy number, where $A_r$ is the most possible quantity of recycling products, $A_r - \varepsilon_r$ is the possible minimum quantity of recycling products, $A_r + \delta_r$ is the possible maximum quantity of recycling products, and $A_r$, $\varepsilon_r$, and $\delta_r$ are all clear numbers. Then, constraint equation (3) could be converted into

$$\sum_{p=1}^{P} x_{rp} = \left(A_r - \varepsilon_r\right) + \theta\left(A_r + \delta_r\right), \quad (12)$$

$$\theta \in [0,1], \quad (13)$$

where $\theta$ is the reliability of the predicted $A_r - \varepsilon_r$ and $A_r + \delta_r$. The value of $\theta$ is determined by experts. Constraint equations (4) – (11) are constant, thus the abovementioned linear programming model with $\tilde{A}_r$ is changed into a parameter programming model that involves the parameter $\theta$. Finally, the converted MILP model is solved by the LINGO 11.0 software.

**Table 1. Construction cost $f_r$, recycling capacity $D_r$, and unit processing cost $OC_r$ at alternative recycling sites $X_r$**

| $X_r$ | $f_r$ (10,000 RMB) | $D_r$ (10,000 pcs) | $OC_r$ (RMB) |
|---|---|---|---|
| 1 | 3.0 | 100 | 0.25 |
| 2 | 4.5 | 200 | 0.2 |
| 3 | 4.0 | 150 | 0.25 |
| 4 | 5.5 | 170 | 0.15 |
| 5 | 4.5 | 150 | 0.2 |

**Table 2. Construction cost $f_p$, recycling capacity $R_p$, and unit processing cost $OC_p$ at alternative remanufacturing sites $Y_p$**

| $Y_P$ | $f_p$ (10,000 RMB) | $R_p$ (10,000 pcs) | $OC_p$ (RMB) |
|---|---|---|---|
| 1 | 15 | 200 | 3 |
| 2 | 20 | 250 | 2 |
| 3 | 25 | 250 | 2 |
| 4 | 30 | 400 | 1.5 |

## 4. NUMERICAL EXAMPLE

### 4.1. Description of the example

A LED manufacturing company decides to launch a self-running reverse logistics business involving waste LED lights, with the main focus on LED modulator tubes (bubbles). The company has 10 primary sales areas and plans to construct five recycling and four remanufacturing sites in these sales areas. The construction cost, maximum recycling capacity and unit processing cost of recycling products of these five alternative recycling sites are listed in Table 1. The construction cost, maximum remanufacturing capacity and unit processing cost of remanufacturing products are listed in Table 2. The unit price subsidy for waste LED recycling is RMB0.1. The transportation cost of the unit product from the recycling sites to the remanufacturing sites is RMB0.1, and the transportation cost of the unit product from the remanufacturing sites to the consumption sites is RMB0.2.

### 4.2. Analysis of the example

With the support of national policies related to green development in recent years, consumers and enterprises have paid increasing attention to the recycling of waste LED lights, thereby increasing the recycling rate $\mu_r$ of waste LED lights to generally not lower than 60 %. When the recycling rate is not lower than 0.6, the model is solved through the software LINGO 11.0, thereby obtaining the output of waste LED lights $A_r$, Table 3. The average remanufacturing rate $\alpha$ of waste products can reach approximately 70 % with the increasing development of the LED lights remanufacturing technology. Meanwhile, the reliability of predicted $A_r$ was determined at 30 % by the negotiation of experts, that is, $\theta$=0.3. After the above parameters are determined, the established model is solved through the LINGO 11.0 software. The results are shown in Table 4.

On the basis of the above operational results, given that $\theta$=0.3, and from the comparison of the optimal costs under different recycling rates, the recycling sites $X_1$ and $X_2$ and the remanufacturing site $Y_2$ are considered for construction when $\mu_r$=0.6, thereby contributing to the minimum total cost (RMB4,393.35). Consequently, the increasing growth of $\mu_r$ will increase the quantities of the recycling sites and price subsidies to products at the recycling sites, thus increasing the total cost accordingly. Organizations, enterprises, and individuals have started to focus on recycling LED lights in recent years, thus increasing $\mu_r$. This scenario reflects that the enterprise that implements the reverse logistics activity have to invest additional costs. Enter-

**Table 3. Production estimation of LED lights at recycling sites $X_r$**

| $X_r$ | $A_r$ (10,000 pcs) | $\varepsilon_r$ (10,000 pcs) | $\delta_r$ (10,000 pcs) |
|---|---|---|---|
| 1 | 15 | 5 | 3 |
| 2 | 20 | 4 | 5 |
| 3 | 17 | 4 | 4 |
| 4 | 17 | 3 | 2 |
| 5 | 17 | 3 | 1 |

**Table 4. Results when $\theta$=0.3 and $\mu_r \geqslant 0.6$**

| $\mu_r$ | $X_r$ | $S_r$ | $Y_P$ | Total cost (RMB) |
|---|---|---|---|---|
| 0.6 | 1,2 | — | 2 | 4393.35 |
| 0.8 | 1,2,3 | 2 | 2 | 4630.43 |
| 0.9 | 1,2,3,4 | 2,3,4 | 2 | 4894.33 |
| 0.95 | 1,2, 4,5 | 2,4,5 | 2 | 5144.63 |

prises should consider the increased production cost because of the construction of the reverse logistics network in addition to the growth of economic benefits caused by the recycling of LED lights. The optimal objective can be achieved if the conflict between the cost and the benefit is balanced, which requires LED manufacturers to measure their own strengths and market development demands carefully, and set the quantity of, locations of, and price subsidies for recycling and remanufacturing sites reasonably when expanding reverse logistics businesses.

## 5. CONCLUSIONS

A multi-objective optimization model of the reverse logistics network of LED lights is established under fuzzy environment and fuzzy recycling quantity hypotheses. This model considers network cost minimization and recycling rate maximization as the objectives. The model is solved through the primary objective method and then is proven valid through a numerical example. This model infers the optimal quantity, locations, and price subsidies for recycling and remanufacturing sites under a fixed confidence coefficient and different recycling rates. This study will help LED manufacturers in setting the locations and network flows of the recycling and remanufacturing sites reasonably from the perspective of economic and environmental benefits. Further studies could involve additional products and explore the dynamic reverse logistics network or the intelligent high-efficiency model for multi-periods.

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# INFLUENCING MECHANISM OF STRONG CONNECTIONS IN LED INDUSTRIAL CLUSTER NETWORK ON ENTERPRISE PERFORMANCE: EMPIRICAL STUDY OF LED ENTERPRISES IN CHINA

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**ABSTRACT**

China has become the world's second largest economy. Given this development, the country's LED industry has a strong potential to become one of the 11 emerging Chinese industries with the brightest prospects. As with any typical knowledge-intensive Chinese industry, strong connections in cluster networks are critical factors that influence knowledge acquisition and elevate the performance of LED enterprises. This study explores the mediating effect of knowledge acquisition in the relationship between strong network connections and enterprise performance using structural equation model. LED enterprises in China were taken as research objects. Results indicate that:

– Strong connections in the cluster network of LED industry have a significantly positive influence on knowledge acquisition;

– Knowledge acquisition has a significantly positive influence on enterprise performance; – Strong connections in the cluster network of LED industry with enterprise performance have an insignificant direct influence.

The relationship between the two variables is conveyed through the mediating effect of knowledge acquisition; that is, knowledge acquisition only plays a mediating role in influencing strong connections in the cluster network of LED industry on enterprise performance. The research results provide insights into the internal influencing mechanism of strong connections in the cluster network of LED industry on enterprise performance through the mediating effect of knowledge acquisition. The results also guide to scientific implementation of enhancing a LED enterprise performance.

**Keywords:** LED industrial cluster, strong network connections, knowledge acquisition, enterprise performance

## 1. INTRODUCTION

The LED industry in China dates back to the 1970s. After 40 years of development, LED industrial clusters were formed gradually in central cities, such as Shanghai and Guangzhou. As the economy of China continuously strengthens, the scale of its LED lighting industry also expands, especially with the increase of global market demand for LEDs. This development promoted the development of China's LED industry. As a typical knowledge-intensive industry, the LED industry is characterized by pronounced technological and knowledge content [1].

LED enterprises in China are limited in scale. Thus, they cannot establish a competitive advantage in the global market by simply relying on their own strength. Therefore, LED enterprises exert considerable effort in seeking industrial cooperation with partners in relevant fields. LED enterprises have adopted various approaches to establish a competitive edge and enable them to effectively cope with market and technological changes. Strong connections in a cluster network are a critical factor that influences knowledge acquisition and promotes improved performance of LED enterprises. In recent

years, the relationship between strong connections in a cluster network and enterprise performance has drawn considerable attention of several scholars [2–5] who focused on exploring the direct relationship between these variables. The relationship between the two variables requires further study. Thus, in the context of China's LED cluster industry, the current study develops a theoretical model of interactions among the strong connections in the LED industrial cluster network, knowledge acquisition, and the performance of LED enterprises. This study explores the mediating effect of knowledge acquisition on the influence of strong connections in LED industrial cluster network on enterprise performance. This study also explores the internal influencing mechanism of strong connections in LED industrial cluster network on enterprise performance through the mediating effect of knowledge acquisition. The results provide a scientific reference for the industrial cluster of LED enterprises to enhance network morphology, knowledge acquisition ability and LED enterprises performance.

## 2. LITERATURE REVIEW AND RESEARCH HYPOTHESIS

### 2.1. Strong connections in LED industrial cluster network and knowledge acquisition

Schutjens used enterprises as node and defined a network as a set of commercial relations between enterprises and retailers, suppliers, contractors, and other co-operators [6]. In terms of network relations strength, Uzzi pointed out that strong network relations will facilitate the technological process innovations of enterprises. Continuous interaction among enterprises not only accelerates knowledge diffusion and sharing in the network, but also leads to the maintenance of strong network connections under an uncertain external environment [7]. Management ability theory based on the perspective of network relations and resources argues that strong network relations can help enterprises to acquire scarce knowledge resources, eliminate resource constraint, and promote development [3]. In addition, Xiumei performed an empirical analysis on the relationship among network capacity, resource acquisition and enterprise performance; this study found that the establishment of network relations and network management ability has significant positive effects on knowledge acquisition and operation of enterprises [4]. Cheng Cong et al. pointed out that enterprises in a network could form a professional division of labour and resource complementation by establishing strong connections, thereby enabling resource acquisition [8]. Li Gang conducted an empirical study on the magnetic system of network relations management ability, knowledge acquisition and service innovation performance of enterprises by collecting data samples of 298 questionnaires from 265 enterprises in Central and East China. He concluded that network relations management ability could promote the external knowledge acquisition of enterprises [3]. Thus, strong network relations accelerate the resource acquisition of enterprises in a network, especially within the LED industry. Chinese LED enterprises are mainly medium-sized and small enterprises. Thus, establishing market and technological advantages in this field will result in the formation of cohesion force by facilitating the industrial cluster effect and promoting cooperation within the network in China. This approach ensures that knowledge and technology can be integrated to accelerate LED industrial innovation. Only then Chinese LED enterprises can achieve a dominant position in the global LED market competition. Therefore, the following hypothesis is proposed.

*H1: Strong connections in the LED industrial cluster network positively influence knowledge acquisition.*

### 2.2. Strong connections in LED industrial cluster network and LED enterprise performance

Numerous scholars believe that strong network relations will directly influence innovation performance and can help enterprises to cooperate, understand mutual demands, explore potential demands and benefits, identify market opportunities, and improve innovation performance [3]. According to Rost, direct and indirect connections in the network have significant positive effects on the technological innovation of enterprises [5]. Cai Ning and Pan Songting claimed that a significant coupling relationship exists in the cluster enterprise network between strong and weak network relations and innovation performance of enterprises; the dynamic situation of connection strength will then influence the technological innovation of enterprises [9]. This finding indicates that strong network relations can

significantly improve enterprise performance. The characteristics of China's LED industry development reveal that numerous LED enterprises will cooperate to improve the current situation of small-scale LED enterprises and address the incomplete industrial chain faced by China. A stable cooperation network contributes to sharing of advanced technology and knowledge among LED enterprises and accelerates the transformation and industrialization of LED technologies. This kind of network promotes the integration of small-scale enterprises in the LED industry, optimizes the LED industrial chain, shortens the time taken and reduces the cost of occupying the global market, and improves the global performance of LED enterprises. Therefore, the following hypothesis is drawn.

*H2: Strong connections in the LED industrial cluster network positively influence enterprise performance.*

### 2.3. Knowledge acquisition and enterprise performance

In a knowledge-driven economy, the influence of knowledge on enterprise innovation, enterprise competitiveness, and enterprise performance is critical and considered a strategic resource of enterprises. Knowledge is scarce and non-replicable; thus, knowledge acquisition can enable enterprises to effectively predict and perceive changes in the external complicated environment and effectively adopt pertinent measures [10]. Zhang Yongjun et al. (2013) argued that the acquisition of external knowledge could contribute to the resource integration of enterprises, enhance the uniqueness of product technologies, improve enterprise-independent innovation ability, and produce core competitiveness [11]. The diversity of knowledge acquisition channels of enterprises directly influences knowledge heterogeneity: the more evident the diversity, the stronger the heterogeneity; improvement in the technological innovation ability and performance of enterprises can then be boosted [12]. Ge et al. argued that knowledge itself and the diversity of source channels contribute to the improvement of the depth and breadth of enterprise learning and provide an effective path for enhancing enterprise performance [13]. Chinese LED enterprises have high knowledge intensity; the advancement of their knowledge and technologies directly determines the regional competitiveness of the LED industry and the way in which the top knowledge point in the LED industrial field provides direction for future efforts of LED enterprises; moreover, knowledge acquisition is a prerequisite and important guarantee for elevating the performance of LED enterprises. The following hypothesis is drawn.

*H3: Knowledge acquisition has a positive influence on LED enterprise performance.*

### 2.4. Mediating effect of knowledge acquisition

Inkpen and Tsang pointed out that strong network relations can facilitate the exchange of knowledge and information among enterprises in the network and help network members to achieve improved technological innovations [14]. Based on the study of transnational joint ventures in industrial clusters, Dou Hongbin conducted an empirical study on related data of 113 enterprises of electronic industrial cluster in Xi'an, China; this study found that the structure of cluster enterprise network can significantly influence enterprise performance through the mediating effect of knowledge acquisition [15]. The unstable linkage of strong connections in industrial cluster networks of Chinese LED enterprises will facilitate further implementation of communication and cooperation. Such a link will also weaken knowledge sharing and transmission effects, which will cause a disorder in enterprises knowledge creation, weaken enterprise knowledge creation level, and obstruct the elevation of LED enterprise performance. Therefore, the following hypothesis is drawn.

*H4: Knowledge acquisition plays a mediating role in the influencing mechanism of strong connections in LED industrial cluster network on enterprise performance.*

The following theoretical model is developed based on the above research hypotheses.

In the theoretical model shown in Fig. 1, four hypothesis paths are formed, namely, the direct influence path from strong connections in LED industrial cluster network to knowledge acquisition, the direct influence path from strong connections in LED industrial cluster network to enterprise performance, the direct influence path from knowledge acquisition to enterprise performance, and the mediating influence path from knowledge acquisition to the relationship between strong connections in LED industrial cluster network and LED enterprise performance.

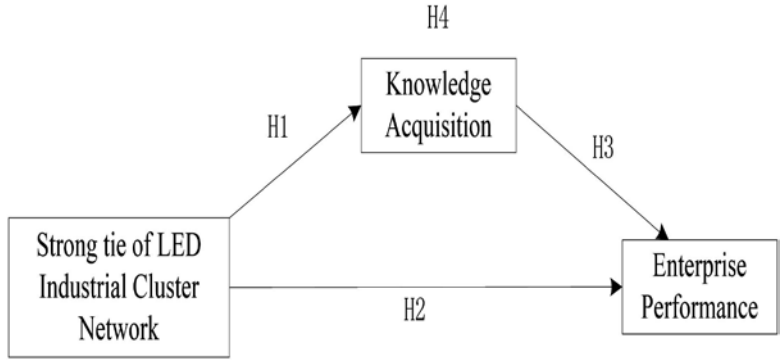


Fig. 1. Theoretical model

## 3. EMPIRICAL RESEARCH DESIGN

### 3.1. Scale design

The design of this research was developed based on previous studies, and was modified according to the current research perspective and expert consultation to ensure its scientific rationality. A seven-point Likert-type scale was adopted for the questionnaire, wherein 1 represents "strongly disagree" and 7 represents "strongly agree". The item for the strong network connections variable was developed following the research design of Caner [16]. The item for enterprise performance variable was developed based on the research design of Love and Roper [17]. The item for enterprise performance variable was developed based on the research design of Vogel [18] and Qian Xihong [19].

### 3.2. Data analysis

#### 3.2.1. Sample characteristics

Questionnaire respondents were 79 relevant enterprises from the LED industrial cluster in Guangzhou, China. A total of 900 questionnaires were distributed from March to July 2016. A total of 779 questionnaires were collected. Incomplete questionnaires were excluded. Finally, a total of 591 effective questionnaires were included in the analysis at an effective recovery rate of 75.8 %. According to geographical locations of the interviewed enterprises, they were mainly distributed in the industrial cluster belt in Guangzhou, China. Based on the enterprise property, state-owned enterprises accounted for 12 % of the interviewed enterprises, whereas private enterprises and overseas-funded enterprises accounted for 88 %. Among the LED industrial chain to which the surveyed enterprises belonged, 11 % of the interviewed enterprises were engaged in the extended field of the LED industry, 18 % were in the chip manufacturing field, and 41 % were in the LED device packaging and production application fields. Moreover, relevant LED enterprises in supporting industries occupied 30 %. Both regional representativeness and enterprise property and industrial type were considered in the selection of questionnaire respondents.

#### 3.2.2. Reliability and validity test

For reliability analysis, this study adopted the Cronbach's coefficient and the global consistency coefficient. According to exploratory factor analysis (EFA), principal component analysis was used to conduct factor rotation and explore the factor structure based on Promax oblique rotation. SPSS17.0 software was used to calculate the reliability and validity of the obtained data of tested groups, as shown in Table 1. Coefficients of latent variables, namely, network strong connections, knowledge acquisition and enterprise performance, were higher than 0.7, which exceeds the suggested value levels.

These values indicate favourable reliability and high dependability of the scale. Findings show further that strong network connections, knowledge acquisition and enterprise performance were factors with eigenvalues higher than 1. Therefore, these three scales had clear factor structures. The accumulative factor variation interpretation rates of all of the variables exceeded 60 %. The factor loading capacities to which the factors belonged were all

**Table 1. EFA of variables**

| Item | Item | Load factor | Cronbach's coefficient alpha | Cumulative explanatory variable (%) |
|---|---|---|---|---|
| Strong network connections | Q1-Q4 | 0.800–0.824 | 0.807 | 65.997 |
| Knowledge acquisition | Q5-Q8 | 0.730–0.863 | 0.801 | 67.864 |
| Enterprise performance | Q9-Q16 | 0.797–0.849 | 0.917 | 67.812 |

**Table 2. Variables of confirmatory factor analysis**

| Index / Variable | $\chi^2/df$ | RMR | GFI | AGFI | NFI | CFI | TLI | RMSEA |
|---|---|---|---|---|---|---|---|---|
| Strong network connections | 2.490 | 0.024 | 0.995 | 0.974 | 0.993 | 0.096 | 0.987 | 0.056 |
| Knowledge acquisition | 0.007 | 0.001 | 1.000 | 1.000 | 1.000 | 1.000 | 1.008 | 0.000 |
| Enterprise performance | 1.435 | 0.018 | 0.992 | 0.974 | 0.994 | 0.998 | 0.996 | 0.030 |

higher than the 0.5 level. Therefore, the scale used in this study has favourable constructive validity.

In addition, to analyse the construct validity of the three potential variables further, confirmatory factor analysis on strong network relations, knowledge acquisition and enterprise performance was performed using AMOS software to verify the fitting indexes of second-order factor models. Results are listed in Table 2.

Table 2 shows that all of the fitting indexes of second-order factor models satisfy the verification standard. This finding indicates that the designed questionnaire has good construct validity.

### 3.2.3. Analysis of model results

Based on the reliability and validity test of the three variables in the previous section, a theoretical model was developed according to the research hypotheses. AMOS7.0 software was used to carry out structural equation model (SEM) testing of the relationships between variables. The test was conducted based on a hypothesis about the mediating effect of knowledge acquisition; thus, a test of the mediating effect principle of Baron & Kenny [20] was adopted, and the test of the mediating effect had three phases with all of the hypothesis tests of relationships among the three variables included. AMOS8.0 software was used to verify the relationships with strong network connections being an independent variable. Knowledge acquisition was considered a mediating variable, whereas enterprise performance was a dependent variable. This study verified the mediating effect of knowledge acquisition on the relationship between strong network connections and enterprise performance. Table 3 presents path coefficients and adaptation indexes of SEMs in all of the phases.

As shown in Table 3, SEM with strong network connections was used as an independent variable, and enterprise performance was used as a dependent variable to verify the mediating effect of knowledge acquisition in Phase 1 of SEM. Strong network connections had a significantly positive influence on enterprise performance ($\gamma 1$=0.742***, P<0.01). In addition, adaptation indexes of Phase 1 of SEM verified by sample data reached the standard values ($\chi^2/df$ =1.353, RMR=0.027, GFI=0.981, AGFI=0.964, NFI=0.985, CFI=0.996, TLI=0.994, RMSEA=0.027). Therefore, H2 is initially verified. In Phase 2 of SEM, strong network connections have a significant influence on knowledge acquisition. The results of the structural equation test with strong network connections as an independent vari-

**Table 3. Test results of the intermediary role of knowledge acquisition**

| Stage SEM | Explanatory variable | Explanatory variable | Path | Coefficient γ value | Path significant results and SEM model test indicator |
|---|---|---|---|---|---|
| SEM 1 | Independent variable | Dependent variable | $\gamma 1$ | 0.742*** | The independent variables and the dependent variable had a significant relationship with path coefficients |
| | Strong network connections | Enterprise performance | | | $\chi^2/df$ =1.353, RMR=0.027 GFI=0.981, AGFI=0.964 NFI=0.985, CFI=0.996 TLI=0.994, RMSEA=0.027 |
| SEM 2 | Independent variable | Mediating variables | $\gamma 2$ | 0.847*** | Argument relationship with the intermediary variable path coefficient was significant |
| | Strong network connections | Knowledge acquisition | | | $\chi^2/df$ =1.608, RMR=0.029 GFI=0.988, AGFI=0.970 NFI=0.987, CFI=0.995 TLI=0.991, RMSEA=0.036 |
| SEM 3 | Independent variable | Dependent variable | $\gamma 3$ | 0.141 | $\gamma 4$ is significant, while $\gamma 3$ is less than $\gamma 1$ $\gamma 3$ path is insignificant, established mediating effects |
| | Strong network connections | Enterprise performance | | | |
| | Mediating variables | Dependent variable | $\gamma 4$ | 0.700*** | $\chi^2/df$ =1.254, RMR=0.030 GFI=0.976, AGFI=0.958 NFI=0.982, CFI=0.996 TLI=0.994, RMSEA=0.023 |
| | Knowledge acquisition | Enterprise performance | | | |

*Note:* ** indicates P <0.05; *** indicates P <0.01.

able and knowledge acquisition as a dependent variable revealed that strong network connections have a significantly positive influence on knowledge acquisition ($\gamma 2$=0.847***, P<0.01). All of the adaptation indexes of Phase 2 reached the standard values. Thus, H1 is confirmed.

In Phase 3, a SEM with strong network connections, knowledge acquisition and enterprise performance as variables was established. Through an empirical test of samples with strong network connections as an independent variable, knowledge acquisition as a mediating variable, and enterprise performance as a dependent variable, strong network connections have insignificant direct effect on enterprise performance (that is, $\gamma 3$=0.141, P>0.1 in Table 3). By contrast, knowledge acquisition had a significant and direct influence on enterprise performance ($\gamma 4$=0.700***, P<0.01). Thus, H3 is verified.

The comparison between Phases 1 and 2 indicates that all of the $\gamma 3$ path coefficients were smaller than the $\gamma 1$ path coefficients. In summary, Phases 1 and 2 satisfied the conditions in Table 3, $\gamma 3$ in Phase 3 of the SEM was smaller than $\gamma 1$ in Phase 1, and $\gamma 4$ was significant, which met Baron and Kenny's test principle of mediating effect. In Phase 3, strong network connections had a direct but insignificant effect on enterprise performance. Therefore, knowledge acquisition only played a mediating role in the relationship between strong network connections and enterprise performance. Thus, H4 is verified.

## 4. RESEARCH CONCLUSIONS AND ENLIGHTENMENT

This study constructed a theoretical model, wherein knowledge acquisition is the mediating variable. This model was constructed by introducing the mediating variable of knowledge acquisition into research on incidence relation between network strong connections and enterprise performance. This study performed an empirical analysis of the mediating effect of knowledge acquisition on the relationship between the strong connections of LED industrial cluster network and enterprise performance. This analysis was conducted in the context of the China's LED industrial cluster in Guangzhou, and was based on collected sample data. Research results revealed the following:

– Strong connections in LED industrial cluster network had a significantly positive influence on knowledge acquisition. In the LED industrial cluster network, strong network connections promoted the information and knowledge sharing of LED enterprises within the cluster, facilitated the formation of the inertia mechanism of knowledge exchange, and accelerated knowledge exploration and acquisition by LED enterprises.

– Knowledge acquisition had a significantly positive influence on LED enterprise performance. Given special requirements for high technological content of LED enterprises, the speed of knowledge acquisition directly influenced the level of enterprise creation. Rapid and stable knowledge acquisition mechanism helped to shorten the time taken to occupy the global market, minimized costs, and improved the enterprise performance level in terms of LED product R&D and production.

– Strong connections in LED industrial cluster network had an indirect influence on enterprise performance through the mediating effect of knowledge acquisition.

This finding means that knowledge acquisition only played a mediating role in the influence of strong connections in LED industrial cluster network on enterprise performance. This finding indicated that numerous enterprises within the LED industrial cluster had complex relationships. Furthermore, cooperation and communication among LED enterprises would form a convention under long-term stable operation only if a foundation of mutual trust was established among cooperative enterprises. This stable communication would enhance sharing and transmission of knowledge. The enterprises would then acquire key technologies and knowledge during knowledge sharing and transmission processes to ensure that enterprise performance is improved.

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# ANALYSIS ON THE INTERNATIONAL MARKETING STRATEGIES OF LED LIGHTING ENTERPRISES IN CHINA

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**ABSTRACT**

Exhaustion of non-renewable resources has prompted continuous human effort to pursue breakthroughs in the field of energy saving. Light emitting diode (LED) lighting has become a major player at the energy-saving market. Many Chinese enterprises have invested heavily in R&D of lighting products. This research studies the market status of Chinese LED lighting enterprises so as to recommend specific international marketing strategies for these enterprises. Marketing theories of foreign and Chinese scholars, as well as the applications of these theories to the LED lighting industry, are summarized first. Thereafter, the development characteristics of Chinese LED lighting enterprises are analysed. These development characteristics are used as a basis to identify the bottlenecks of the LED lighting market of China. Lastly, the development prospects of China's LED lighting are discussed. Findings suggest that Chinese LED lighting enterprises are characterized by high intellectuals, high capital investments, high risks, and high intensity of competition. "Physical stores" are still major sales channels for Chinese LED lighting enterprises. However, excessive differentiation of products has hindered the formation of popular Chinese LED lighting brands. Accordingly, the sales terminals of lighting products lack diversity and lighting enterprises lack innovation; thus, these enterprises are generally engaged in cost competition. Problems with the four preceding aspects are major development bottlenecks of China's LED lighting market. In terms of China's LED lighting market development prospects, the overall market scale will continue to expand, industrial reforms will bring new business opportunities, and environmental policies of the government will fuel further development, residential consumption level, and structure upgrading. Given the development status and prospects of China's LED lighting industry, Chinese LED lighting enterprises can increase their overall competitiveness through international marketing strategies, including increasing government support for the LED lighting industry, providing opportunities to the leading role of China LED Lighting Industrial Association, and improving corporate core competitiveness. Findings of this study provide valuable references for the discussion of problems that face the international marketing of Chinese lighting enterprises, and for the formulation of feasible international marketing plans.

**Keywords:** LED lighting enterprise, international marketing, strategy research

## 1. INTRODUCTION

In China, the lighting industry has been listed as one of strategically emerging industries that deserve government support. The thriving lighting industry of China has prompted many Chinese enterprises to invest in lighting projects. However, a set of mature regulations and systems has yet to be developed in China. Moreover, the Chinese lighting

industry is still faced with excess production capacity. Thus, many products have to be sold overseas to avoid overstocking. Undoubtedly, China's lighting industry has competitive advantages in terms of raw materials and labour force. These two advantages have created favourable conditions for exporting lighting products. Nevertheless, one fact should not be ignored, that is, the lighting industry has developed in China for just a dozen of years. Conceptually, this industry is still emerging in China; thus, many improvements should be implemented. International marketing strategies are no exception. Two issues that have become immense concerns of Chinese lighting enterprises are how to accelerate the recognition of Chinese lighting products at the international market and how to build international lighting brands of China.

## 2. LITERATURE REVIEW

McCarthy proposed a popular concept of the 4Ps marketing mix (i.e., 4Ps include "product," "price," "place," and "promotion"). Magrath introduced the idea of "megamarketing" and further extended McCarthy's 4Ps into 10Ps [1]. Nefat analysed the influence of marketing theories on company profitability by considering that companies in Croatia generally accepted the marketing philosophy. His findings verified that absorption of marketing concepts could contribute to an increase of company profitability [2]. Grigoryan conducted a comparative study of major differences and similarities of the B2B marketing in the US, EU, and Japan [3]. Lages studied international marketing strategies in four dimensions, namely, product, promotion, price, and sales strategies, and used a sample survey to conclude that marketing strategies that cater to the development needs of these four dimensions are influenced by the financial resources assigned by a company for export activities [4]. Paswan collected marketing and channel management data of American pharmaceutical enterprises, and results suggested that the management of marketing channels (from the management perspective) is the linchpin to successful implementation of marketing strategies [5]. Vranceanu studied prices at the retailer market of Romania and proposed that price can influence customer's perception of product image and their purchase intentions [6]. In terms of marketing research of LED lighting enterprises, Tsao explored the development planning route of the LED lighting market in 2010 and proposed the corresponding policy suggestions [7]. Devonshire focused on the market competition that faces LED lighting techniques [8]. Adkins conducted a case study of LED lighting as part of the Millennium Village Project in Malawi; he argued that LED lighting can facilitate the improvement of local environmental protection [9]. Bessho expounded on the latest development trend in LED lighting and defined marketing as one of the core capabilities of LED lighting enterprises [10].

The preceding literature review indicates a general agreement on major sales approaches of LED lighting enterprises, that is, to sit still and wait for customer orders. Moreover, the product sales terminals lack diversity. LED lighting enterprises are often passive in the area of promotion. Even if sales promotions exist, innovation is lacking. The Chinese LED industry focuses on the most difficult application field, which directly influences the export of lighting products. Substantial government interventions considerably hinder the fair play of lighting enterprises at the international market. Lastly, the current LED lighting industry lacks qualified professionals.

## 3. DEVELOPMENT CHARACTERISTICS OF CHINA'S LED LIGHTING ENTERPRISES

### 3.1. Need for intellectuals

The competition among contemporary LED lighting enterprises is mainly reflected as a competition at the technological level and product update. In the final analysis, the competition among talents and intelligence matter as well. To seek an improved development, any LED lighting enterprise cannot be separated from an efficiently operating technological and management team. The technological team often comprises talents in different technological fields, such as semiconductor materials, organic chemistry, and analysers. By contrast, the management team is replete, among others, with proficient talents in corporate operation, financial management, and marketing. Meanwhile, talents who know techniques and have management expertise are needed. In essence, the process of enterprise industrialization is a process of talent development. Intellectuals develop in the real industrial environment.

### 3.2. Need for high capital investments

Ample capital supply is a significant material guarantee for LED lighting research, development and industrialization. Enterprises should take the initiative to invest in R&D due to the rapid technological development of the LED lighting industry. At present, many enterprises fail in their attempt to industrialize mainly because of inadequacy of capital. The traditional industrial development model can hardly achieve successful industrialization for enterprises. Similar to talents, capitals are essential for the development of LED lighting enterprises, thereby providing material guarantee for technological advances of the latter.

### 3.3. High risks

High risks faced by the LED lighting industry are mainly reflected as the uncertainty of LED lighting R&D in the exploratory period. The high failure rate of R&D indicates that technological achievements may not be necessarily commercialized and transformed into material fortunes. Market demands are ever-changing, and market competition is intensifying. Many uncertain factors influence product recognition and investment return. Brain drain has become a serious problem facing the LED lighting industry because of high risks, thereby increasing the corporate technical training cost and uncertainty of technological development and protection. The substitutes for LED lighting products are gradually maturing, thereby challenging the market positions of LED in specific fields.

### 3.4. High intensity of competition

LED lighting products with high technological content, rapid technological advancements and robust market demands provide lucrative business opportunities in China. In recent years, an increasing number of Chinese LED lighting enterprises have invested in R&D of LED lighting products. The investment initiatives of these enterprises have provided them with a foothold in the LED lighting market. The success of these enterprises has attracted new entrants, thereby resulting in intense competition. In fact, the situation in China is exclusive. Other countries have introduced numerous resources to develop the LED lighting industry. Accordingly, the worldwide investment fervour has led to global intensification of competition in the LED lighting industry. Therefore, any enterprise that joins the industry has to cope with international competition. The dominance of several technologically powerful and time-honoured brands at the international market has increased the difficulty for Chinese LED lighting enterprises to establish their international presence. Overall, the LED lighting industry has become an international industry that knows no borders and is not under any protection of trade barriers.

## 4. DEVELOPMENT BOTTLENECKS OF CHINA'S LED LIGHTING MARKET

### 4.1. Physical stores: A major sales approach for most Chinese LED lighting enterprises

At present, most of Chinese LED lighting enterprises sell lighting products through physical stores. The awareness of actively building sales channels and expanding the international market has yet to be developed. Most of these enterprises sit and wait for customer orders, and the sales approach is considerably passive. Only a few lighting brands, such as Opple and Matsumoto, have developed their own sales teams and built their domestic sales network. The rest generally lacks sales teams let alone an established overseas sales network.

### 4.2. Excessive product differentiation: Difficulty of developing popular brands

Chinese LED lighting enterprises, particularly those manufacturing nonstandard lighting products, attach considerable importance to uniqueness and promotion speed of lighting product styles. Every product type has a small output. Most of the assembly lines are left idle, but the trial manufacturing workshop of the R&D department is constantly bustling. Furthermore, the brands of many Chinese LED lighting enterprises are merely company names. However, foreign customers value the brands of enterprises. Evidently, the branding of Chinese LED lighting enterprises has yet to form an international influence. The lack of proprietary brands has resulted in difficulties for Chinese LED lighting enterprises to compete with leading international lighting brands, such as FORNZASI-ER (Italy), VIBIA (Spain), and KICHLER (US). This situation has resulted

in a substantially short product life cycle of Chinese LED lighting enterprises.

### 4.3. Lack of diverse sales channels for lighting products

At present, LED lighting dealers throughout China concentrate on building a wholesale market or a market segment of wholesale lighting. The sales forms are extensive. Local and overseas customers opt for the current lighting market or directly order from the production and distribution centres based on their demands. Manufacturers of standard lighting products have diversified their terminals, but those of nonstandard lighting products have a different story. Hence, the latter experience difficulties in forming long-term partnership with foreign enterprises let alone customer loyalty shaping.

### 4.4. Inadequacy of innovation and intensity of cost competition

The LED lighting industry is an industry with low technological barriers. The more developed the accessory manufacturers are, the more transparent the cost constitution of LED lighting manufacturers is. Experienced distributors often visit the lighting accessory market first to learn the base prices of accessories, and bargain with the lighting product manufacturers thereafter. Enterprises can hardly build their advantages due to the transparency of prices. Several international LED lighting brands have invested in R&D of product materials and types to radically improve their competitiveness.

## 5. DEVELOPMENT PROSPECTS OF LED LIGHTING MARKET IN CHINA

### 5.1. Large market scale

LED lighting with considerable advantage has become an outstanding player in new energy industry. In the future, the LED industry will witness new applications. Accordingly, new sealing technologies and chips will be used to cut production costs and increase luminous efficacy. The pace of development of the LED lighting industry relies on the market acceptance of luminous efficiency, product quality, and innovation. At present, customer demands of the LED general lighting market have shifted from luminous efficacy and attractive price to quality, environmental protection, and comfort. In the future, environmental friendliness will attract substantial attention, and the price of LED lighting products will be decreased further.

### 5.2. New opportunities brought by industrial reforms

Advertising input is increasing along with the continuously steady development of the Chinese economy, enrichment of consumables, and intensification of market competition. This situation has led to continuous expansion of the advertising market. Although outdoor advertising has achieved an annual increase, its overall growth has been gradual. Meanwhile, new scenarios, including cinemas, elevators, subways, and shopping centres, for new media advertising have been diversifying. The digitalization of outdoor media marketing and upgrading of customer perception and interactivity will inevitably launch industrial reforms. The development of the O2O marketing in China has provided a profound lesson on network marketing for domestic small- and medium-sized advertisers. O2O is currently emerging as a core force in developing marketing models in China, including social network and scenario marketing. Mobile equipment provides enterprises with user location information. Mobile marketing service providers use location-based service and big data to accurately attract offline customer flows and facilitate O2O operation. Meanwhile, mobile marketing service providers have used social media to assist local advertisers to realize the long-term and multi-frequency marketing activities among local users. Overall, O2O can transfer online visitors into offline consumers at a substantially low cost.

### 5.3. Promotion of government environmental policies

Experience has shown that digital marketing is about to overtake conventional marketing. Moreover, changes in information communication patterns brought by new media have increased the prominence of the integration trend between communication and marketing. The boundary between PR and advertisements is disappearing. PR services are ushered into the transitional development period of content-driven integration between mass communication and marketing. Furthermore,

PR enterprises are highly likely to be the first movers in the transitional period, thereby reshaping the room for industrial development. The Chinese government is encouraging the development of the advertising industry. Numerous industrial policies, including the "Twelfth Five-Year Plan for the Advertising Industry," have achieved enormous strides for China's advertising industry in recent years. Outdoor advertising is a significant component of the advertising industry, and will undoubtedly obtain government policy support. In addition, the revolutionary development of digital and network transmission techniques has led to a substantial increase in the amount of information and the number of communication channels. Combined applications of various new techniques will generally improve the communication effects of marketing information.

### 5.4. Improvement of the resident consumption level and structure

Changes in residential lifestyle and consumption habits can directly influence the communication effects of media. Internet advertising, outdoor media representatives, such as traditional outdoor advertisement billboards and LED screens, and marketing that emphasizes on audience experiences cater to contemporary lifestyles and living habits. Impressive communication effects are popular with contemporary advertisers. Enterprises committed to providing quality marketing communication services should build a multi-dimensional and accurate communication network that can effectively increase the number of channels and the probability to attract the attention of target consumers. Consumer demands can be substantially satisfied, and enterprise competitiveness can be elevated to a new level.

## 6. INTERNATIONAL MARKETING STRATEGIES FOR CHINA'S LED LIGHTING MARKET

### 6.1. Increase government support for the LED lighting industry

Chinese government should change the development direction by guiding LED production and export to start from indoor lighting with low technical threshold. Chinese LED lighting enterprises would take time to mature. In response to the new situation in which industry, commerce, and quality supervision are closely combined, the relevant Chinese departments should readjust and improve their quality management system. For example, the supervision of LED lighting enterprises should be strengthened, and the entire process from in-warehousing of materials to out-warehousing of completed products should be under supervision and guidance. In light of international market situations, the key supervision points of LED lighting products should be immediately adjusted to avoid substandard LED lighting products from flowing into the international market. In addition, the Chinese government should support and encourage LED lighting manufacturers to introduce and accept advanced foreign techniques and management experiences, as well as search and publicize international trade information on LED lighting products, develop risk awareness, and avoid blind production and export. These strategies can ensure LED lighting products made by China to enter the international market with an "ecological," "legitimate," and "safe" image. Chinese government should simplify the handling formalities and create multiple exchange platforms for domestic LED lighting enterprises. This way, Chinese entrepreneurs can establish LED lighting groups easier. Meanwhile, the Chinese government can further consider business attraction in accordance with local economic and research situations. Given that small and scattering enterprises gather in an industrial zone, the cluster effect will be shaped to bring scale advantages to enterprises in the industrial zone. This strategy can endow enterprises with price competitiveness, through which substantial international market share can be obtained and potential markets can be explored.

### 6.2. Provide opportunities to the guiding role of the China LED Lighting Industrial Association

The China LED Lighting Industrial Association can refer to advanced management experiences of their Western counterparts. By strengthening the corresponding institutional construction and providing opportunities to the service function of the industrial association, this group can become a beacon for international marketing of Chinese LED lighting enterprises. The China LED Lighting In-

dustrial Association can build a complete project information database to share the latest trends of the international market with member enterprises. Meanwhile, project information overseas and marketing intentions of enterprises in different regions of China should be collected to build regional and national marketing environments, as well as legal and policy information databases. All member enterprises can have access to the database, thereby avoiding losses caused by information asymmetry and alleviating the blindness of member enterprises in terms of export practices. Given that many Chinese LED lighting enterprises have yet to develop completely, their legitimate rights and interests are often damaged at the international market. Accordingly, the China LED Lighting Industrial Association can endeavour to safeguard the international marketing order, strengthen coordination and monitoring of domestic market and price, and increase information sharing. In addition, leading Chinese LED lighting enterprises should be invited as members, thereby enabling other domestic counterparts to learn from the former and obtain the latest international market information. Member countries should be encouraged in terms of proprietary innovation. The industrial cluster can enhance innovation, and cooperation between enterprises and scientific research institutions can be expanded to obtain additional core production techniques. Vigorous support should be provided to Chinese LED lighting enterprises to form partnerships with foreign counterparts. The advanced techniques and management expertise of the latter can contribute to narrow the gap between Chinese and foreign LED lighting enterprises in terms of operation, management, product quality, and brand influence. Additional policies should be formulated to attract numerous member enterprises to international cooperation.

### 6.3. Improve core competitiveness of LED lighting enterprises

If Chinese LED lighting enterprises want to establish their own international brands, then they should develop a group of loyal customers at the international market. Accordingly, maintaining customers rests on these enterprises' continuous improvement of core techniques. On the one hand, business elites of enterprises should be selected as backbone staff to provide technical services. On the other hand, technical talents can be introduced from foreign countries. In addition, Chinese LED lighting enterprises should develop their own R&D centres. Proprietary R&D of new products can attract numerous customers and promote the development of China's LED lighting industry. Meanwhile, Chinese LED lighting enterprises should actively develop into industrial leaders to dominate the domestic or even the global LED lighting industry. Experience shows that if the Chinese LED lighting product design, packaging, and marketing can be combined with the culture of the target market, then impressive sales performance can be achieved. Chinese LED lighting enterprises that attempt to "go global" should improve their competitiveness, concentrate on the improvement of product quality, abandon the price war, and produce substantially satisfying and quality products for the foreign market. This way, Chinese LED lighting enterprises will maintain long-term and stable relationships with foreign customers.

## 7. CONCLUSIONS

The strengthening appeal of environmental protection and energy conservation has led governments around the world to realize the importance of LED lighting. Accordingly, the economic and energy-saving benefits brought by LED lighting have attracted many Chinese manufacturers. This study analyses the development characteristics of Chinese LED lighting enterprises, summarizes the development bottlenecks of the LED lighting market, and evaluates the development prospects of the LED lighting market in China. The four characteristics of Chinese LED lighting enterprises are the need for qualified intellectuals, the need for high capital investments, high risks, and high intensity of competition. In terms of development bottlenecks, the four include "physical stores" as the major sales approach, excessive product differentiation impeding the development of popular brands, lack of diversified lighting sales terminals and lack of innovation that leads to the intensification of cost competition. Despite the presence of development bottlenecks, the LED lighting market of China exhibits brilliant development prospects, including a large market scale, new opportunities brought by industrial reforms, government policy support and improvement of resident consumption level and structure. Given the development status, bot-

tlenecks, and prospects of the LED lighting industry in China, this study proposes several international marketing strategies for Chinese LED lighting enterprises. First, the Chinese government should increase its support for the LED lighting industry. Second, the guiding role of the China LED Lighting Industrial Association should be provided with opportunities. Third, the core competitiveness of LED lighting enterprises should be upgraded to a new level. Evidently, this study has limitations as well. Although we focused on the international marketing strategies for Chinese LED lighting enterprises, this study fails to conduct in-depth research on the methods of improving production techniques, service and product quality, sharpening brand awareness, upgrading corporate management level and brand awareness, and deepening the competitive strength. These areas call for research attention in the future.

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# DUAL−CHANNEL INTEGRATED MARKETING STRATEGY FOR LED LIGHTING PRODUCTS

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**ABSTRACT**

Prosperous development of the e-commerce market drives enterprises to improve their industrial layout, continuously seek for new developments and new markets, and increase their comprehensive competitiveness through resource integration and business innovation. Many LED lighting product manufacturers have established online marketing channels based on traditional retail channels to meet consumer demands. They integrate the advantages of online and offline channels to improve market competitiveness. However, opening two types of channels, namely, online and offline, causes retailers from online direct sales and from offline channels to become direct competitors, and this results in channels conflict. In the e-commerce era, implementation of the dual-channel strategy is inevitable if we want to conform to development. This study applied online and offline resource integration with retailers as the analysis subject. Simulation and constraining mechanisms were designed to facilitate information integration and moral risk restriction. This study has implications for dual-channel integration and complicit alleviation.

**Keywords:** dual channels, information integration, moral risks

## 1. INTRODUCTION

A relatively stable urban space inevitably leads to shortage of energy and resources [1]. The government attempts to increase the share of renewable and new energy sources [2]. LED light sources, which provide a new type of lighting, have longer service life than ordinary light sources. However, LED products entail high production costs, and their prices are generally 5 to 10 times higher than those of ordinary light sources. Consumers lack knowledge on the product features and application status of LED light sources, so market promotion of these products is not ideal. China provides a favourable environment for e-commerce development. With the promotion and popularization of social network sites, and the diversification of consumer demand, overseas and online social shopping have emerged and subdivided online shopping markets. Many LED lighting enterprises have begun adopting multi-channel marketing strategies, including network, physical store, and engineering channel marketing, due to the development of e-commerce; they do so to expand their market shares under favourable policies. Direct sales channels of LED lighting products can be classified into two major types, namely, online (e-commerce) and offline.

Manufacturers use multiple channels to cater to the purchase motives of different consumers. By providing multi-channel selection for consumers, manufacturers create benign competition, increase client bases, and improve consumer loyalty [3]. Improved living conditions are the most important factor in China's increased energy consumption [4]. Limited cooperation, competition, conflict, or disharmony among channels, negatively affect the purchasing intention of clients. Channels conflict may be caused when traditional retailers broaden online channels (i.e., one channel encroaches on another channel) [5]. Faced with total energy consumption,

domestic enterprises should play the role of a mainstay [6]. When LED lighting product manufacturers simultaneously adopt offline and online channels, the online electronic channels can increase profits and market demand. Hence, manufacturers can attract consumers with maximum values in intermediate channels. If the market position of retailers is threatened, a "price war" may occur between channels. Furthermore, offline channel retailers may exit from the market, and demand and profit would decrease as a result. During multi-channel marketing of LED lighting products, competition between channels results in reduced benefits for traditional channels, thus relieving that the conflict of interest and enhancing the coordination between channels are crucial [7].

## 2. STATE OF THE ART

Collaboration is generated through resource sharing among independent constituent parts, which then become interdependent and grow together. Group business performance is formed through a simple summarization of enterprise activities. Schröder and Zaharia analysed the importance of collaboration when consumers make purchase decisions from multiple channels of the same enterprise [8]. The first step to create a consumer-centred multi-channel system is a synchronous usage, and collaboration among channels has greater significance in the multi-channel system than in the channel-parallel retail mode [9].

Supply chain integration is significantly correlated with the operational performance of supply chains and participating enterprises. The design of supply chains exerts a positive influence on supply chain integration and the performances of these supply chains [10]. Collaboration in multi-channel integration is manifested by attracting new consumers through newly added online services, and it contributes to differentiation of added values, improves consumer loyalty, increases the sales volume, and reduces cost [3]. Reducing the unit variable operation cost of a channel can effectively enhance the preference of consumers for this channel, expand the difference between channels, and increase the balanced sales volume of the channel. Brand awareness also influences collaboration between channels. Pauwels confirmed through a regression equation that for a well-known brand, internal collaboration among online channels is higher than dual-channel collaboration. For products with low brand awareness, increased collaboration can be obtained through offline channels [11]. From the perspectives of product attributes and market complexity, Wong et al. found that supply chain information integration is for the benefit of enterprise performance enhancement when simple products are provided or in a market environment with high complexity [12].

Many studies have been conducted on dual-channel coordination through a price strategy. Retailers can coordinate dual channels through an appropriate pricing strategy and channel combinations, and integrating online and offline channels in different periods can solve channels conflict [13]. Berman and Thelen indicated that strategies can be formulated from multiple aspects, such as product consistency, enhanced integration of client information and sales promotion, trans-channel pricing and inventory information and providing multi-channel searching opportunities, so as to obtain improved multichannel integration [14]. Xie et al., through an analysis of computational examples, discussed dual-channel coordination, formulated a dual-channel gain sharing mechanism, and obtained online and offline wholesale prices and advertisement investment [15]. Li et al. applied game theory to explore the influence of retailer risk indicators on retail price and the total profit of the supply chain. They proposed coordinating the dual-channel supply chain through risk sharing [16].

With existing research as a basis, and starting from the perspective of virtual resource integration, this study discussed incentive and constraint mechanisms of dual-channel information integration. The aim is to relieve channels conflict and facilitate collaboration between dual channels.

## 3. MODELLING

### 3.1. Incentive mechanism

Investment in the information system of a dual-channel supply chain is in a market contract form. Therefore, the investment and operation of the information system of an integrated dual-channel supply chain become a technical contract between manufacturers and other upstream and downstream participating enterprises. The technical contract between integrative subjects in the dual-channel supply chain entails a high sunk cost, and the infor-

mation system value of the dual-channel supply chain after integration is a contract value. When the investment placed by the contract value on the information system reaches a certain application level, the technical barrier characteristics are degraded, and the contract value is manifested as the contracting cost with the characteristics of a sunk cost.

Model preconditions: Enterprise "A" is a LED lighting product manufacturer that adopts dual-channel direct sales. Its upstream supplier is enterprise "B". The sales channels of LED lighting products are divided into online C1 and offline C2, and the assumption is that the distributor sells the products of manufacturer "A" only, and the connection cost of all dual-channel marketing channels is zero. In this study, the dual-channel integration mode adopts integrated dual channels, namely, the online channel of the manufacturer belonging to the self-supporting electronic marketing channel and the offline channel belonging to retailers under independent operation. Hence, in the discussion of dual-channel marketing information integration, only the spillover effect when offline channel retailers participate in value creation of the supply chain system is considered.

***Hypothesis***: The integration of information systems between a LED lighting product manufacturer and its supplier generates the network spill over effect and improves the inventive functions of the retailers participating in the integration of the dual-channel marketing information system.

***Proof:*** LED lighting product manufacturer "A" and its upstream supplier "B" participating in the information integration have already reached a strategic cooperation alliance. The supply chain information system has already improved the transmission and production efficiency of supply chain information, and has reduced collaborative operation and transaction costs between enterprises. After offline retailer "C" participates in the supply chain information system, the manufacturer can offer its products at a reduced price while increasing the replenishment and supply speeds. At this moment, retailers can acquire higher profits than those obtained when they do not participate in the information system integration. That is, integration of the supply chain information system between the manufacturer and supplier generates a spill over effect, elevates the retailers' value expectation for participating in the information system integration of the manufacturer, and realizes value appreciation of virtual resource integration of dual-channel supply chains.

The profit of offline retailers is expressed as,

$$\pi_c = (p - e^{1-\partial} w)q, \tag{1}$$

where $p$ is the product price, $q$ is the product sales volume, and $e^{1-\partial} w$ is the minimum product wholesale price obtained by offline retailers from LED lighting product manufacturer "A". The information system integration density of the entire supply chain is expressed by $\partial$, and $0 \le \partial \le 1$. The greater the integration density of the information system, the lower the wholesale price $e^{1-\partial} w$ obtained by offline retailers and the greater the profit $\pi$.

Information system integration density $\partial$ of the entire supply chain refers to the joint participation of the supplier, manufacturer and offline retailers, so integration density $\partial_{ABC}$ of the overall information system should be greater than integration densities $\partial_{AB}$ and $\partial_{AC}$ when the manufacturer participates with its suppliers and retailers, respectively. $\partial_{\bar{B}}$ is used to indicate that the supplier does not participate in the integration of the supply chain information system. Then,

$$\pi(C|\partial_{ABC}) \ge \pi(C|\partial_{\bar{B}}) . \tag{2}$$

For offline retailers, the spill over value when participating in information system integration is:

$$\Delta\pi_C = \pi_{\partial=\partial_{AC}+\partial_{AB}} - \pi_{\partial=\partial_{AC}} = wqe^{1-\partial_{AC}}(1-e^{-\partial_{AB}}). \tag{3}$$

As shown in the above equation, the spill over value generated by the retailers when the supplier and LED lighting product manufacturer participate in information system integration has a positive correlation with integration density $\partial_{AB}$ between the manufacturer and supplier.

Before the manufacturer in the dual-channel supply chain conducts information system integration, the manufacturer cooperates with the supplier and retailers in information system integration ( $\partial = \partial_{AC} + \partial_{AB}$). The profit of the offline channel retailers is

$$\pi = (p - e^{1-\partial_{AC}-\partial_{AB}} w)q. \tag{4}$$

Then the manufacturer and supplier enhance information integration density: $\partial_{AB} \to \partial_{AB}'$ and

$\partial_{AB}' > \partial_{AB}$. The profit of the retailers is transformed into

$$\pi' - \pi = (p - e^{1-\partial_{AC}-\partial_{AB}'} w)q - (p - e^{1-\partial_{AC}-\partial_{AB}} w)q, \quad (5)$$

namely

$$\Delta\pi = wqe^{1-\partial_{AC}}(e^{-\partial_{AB}} - e^{-\partial_{AB}'}), \quad (6)$$

$\partial_{AB}' > \partial_{AB}$, and $e^{-\partial_{AB}'} < e^{-\partial_{AB}}$. Thus, $\Delta\pi > 0$. Enhancement of information integration density between the supplier and manufacturer and the connection between information networks will form a positive value spill over to retailers.

During the actual dual-channel integration process, the manufacturer and supplier conduct information integration and share product performance and quality information. They can rapidly feed product quality problems to the supplier, improve quality in a timely manner, and begin implementing monitoring and management of product quality in the production phase of raw materials. After the establishment of a collaborative production between the supplier and the manufacturer, they can accurately formulate production plans and reduce their own inventory costs. The effect of collaborative production lowers the production cost, increases the speed, at which the enterprise responds to the market, and makes offline retailers experience a spill over effect of information integration.

### 3.2 Constraint mechanism

During the integration process of the dual-channel supply chain, moral risks easily occur in the initial channels integration phase. These risks include concealing actions, concealing information, moral risk of the manufacturer, and moral risk of offline channel retailers. During the dual-channel integration process, after the manufacturer and retailers in the offline channel reach an agreement over the integration, the economic activities of the retailers are asymmetric with those of the manufacturer. That is, only retailers select enterprise activities alone, and the manufacturer can only observe the results of actions and cannot observe the actions themselves. Hence, during the integration process, the selection made by the retailers is related to the benefits of the manufacturer.

*1. Necessary condition for the operative constraint*

In the establishment of a constraint mechanism of moral risks of the dual-channel supply chain, this study incorporates fairness theory into the constraint mechanism. We assume that during the dual-channel supply chain integration process of the LED lighting product manufacturer, the comparison result of the ratios of remuneration $O$ to contribution $I$ of the participants to the supply chain with those of others is used as a criterion to be satisfied, namely, it is satisfied if the two are equal. When the constraint mechanism is operative, the ratio $O_A / I_A$ of punishment $O_A$ to loss $I_A$ caused by immoral behaviour of retailer "A" to the manufacturer should be borne by the retailer according to the contract and should be equal to $O_B / I_B$ of retailer "B", namely,

$$\frac{O_A}{I_A} = \frac{O_B}{I_B} = \frac{O_C}{I_C} = \ldots = k, \quad O_A = kI_A(k > 0). \quad (7)$$

Then, in a fair market competition environment, the necessary condition for the operative constraint in the constraint mechanism of the dual-channel supply chain integration is $O = kI(k > 0)$, namely, the punishment borne by the offline channel retailer is in direct proportion to the overall loss caused by the retailer to the overall dual-channel supply chain.

$O$ is the punishment imposed by the dual-channel supply chain on offline retailers, and $I$ is the loss caused by the individual risks of retailers to the overall dual-channel supply chain, including economic and reputation losses. As the core subject in the integration, a LED lighting product manufacturer can utilize its power in the dual-channel supply chain to setup a violation punishment system to constrain the behaviours of offline channel retailers.

*2. Sufficient conditions for the operative constraint*

During the collaborative operation of the dual-channel supply chain, the offline opportunistic behaviours of retailers are usually covert and not easily perceived, especially in a benefit-sharing contract based on the collaborative operation after the integration of the dual-channel supply chain. When the operating activities of the online channel pose

a threat to the offline channel, offline retailers adopt several behaviours to ensure their own benefits. The probability of an opportunistic behaviour of the retailers to be found and punished is $p_1$, the utility of the punishment caused by this behaviour on retailers is $a_1$, the probability of the success of this opportunistic behaviour is $p_2$, and its utility for the retailers in the offline channel is $a_2$. When the utility of the retailers being found and punished is greater than that of the retailers not being found, namely, when $a_1 p_1 > a_2 p_2$, operative constraints can be implemented on retailers.

Sufficient conditions for operative constraints in the collaborative operation of the dual-channel supply chain are:

$$a_1 > \frac{a_2 p_2}{p_1}, p_1 + p_2 = 1, 0 < p_1, p_2 < 1. \tag{8}$$

The sufficient condition for the operative constraint of the constraint mechanism of moral risks is:

$$a_1 = \lambda \frac{a_2 p_2}{p_1} (\lambda \geq 1). \tag{9}$$

*3. Model design of the constraint mechanism of moral risks*

$a_1 = \lambda \frac{a_2 p_2}{p_1} (\lambda \geq 1)$ is a sufficient condition for the operative constraint of the constraint mechanism of moral risks, but $a_2$ is more difficult to perceive. $a_2 = u_2 + u_2'$ is set, where $u_2$ is the utility when retailers are found with opportunistic behaviours and punished, and $u_2'$ is the utility of the unexamined punishment amount for violation on retailers.

$$\begin{aligned} u_2 = a_2 p_1, u_2' = a_2 p_2, \\ u_2' = (1 - p_1) a_2, a_2 = \frac{u_2'}{p_1}. \end{aligned} \tag{10}$$

The following is obtained according to the fairness conditions:

$$\begin{aligned} a_1 = k a_2 = k(u_2 + u_2') = k[u_2 + (1 - p_1) a_2] = \\ = k(u_2 + \frac{1 - p_1}{p_1} u_2) = k_1 u_2. \end{aligned} \tag{11}$$

If $p_1$ is a constant punishment utility, $a_1$ is in direct proportion to the violation amount, when the retailer behaviours are not successful.

The sufficient condition for the operative constraint of moral risks of the dual-channel supply chain when punishment intensity $a_1$ is fixed is shown below:

$$a_1 = \lambda \frac{(1 - p_1) a_2}{p_1} = \lambda \frac{(1 - p_1)}{p_1^2} u_2 (\lambda \geq 1). \tag{12}$$

Similarly, the fairness conditions of the constraint are met.

For any $p$, $a_1 = \lambda \frac{(1 - p_1)}{p_1^2} u_2$ meets the fairness and sufficient conditions of the constraint. Given that retailers in the offline channel have limited economic capability, and $L$ is assumed to be their capability, the punishment they can bear is also limited. Thus, the following is met:

$$a_1 = \lambda \frac{(1 - p_1)}{p_1^2} u_2 < L. \tag{13}$$

If $\lambda = 1$, then

$$p_1 > \frac{[-u_2 + \sqrt{u_2^2 - 4 L u_2}]}{2L}. \tag{14}$$

Given that $0 < p_1 < 1$, then

$$0 < \frac{[-u_2 + \sqrt{u_2^2 - 4 L u_2}]}{2L} < 1. \tag{15}$$

For maximum punishment intensity $L$ that can be borne by offline retailers, we should examine whether $p_1 > \frac{[-u_2 + \sqrt{u_2^2 - 4 L u_2}]}{2L}$ is true; if it is not true, supervision of the intensity of the retailer operating activities should be enhanced to ensure that this equation is true.

$C(p_1)$ is the cost paid by the manufacturer when the probability of the manufacturer finding out the legal risk-taking behaviours of offline retailers is $p_1$, and $C(p_1) = np + C_0$. The actual loss of the manufacturer is:

$$U(p_1) = a_2 - a_1 + np_1 + C_0 = \frac{u_2}{p_1} + np_1 + C_0. \quad (16)$$

According to sufficient condition $a_1 \geq \lambda \frac{(1-p_1)}{p_1^2} u_2$ for the constraint mechanism of the moral risks of dual-channel supply chain,

$$U(p_1) \leq a_2 - a_1 + np_1 + C_0 = \\ = \frac{u_2}{p_1} - \frac{(1-p_1)}{p_1^2} u_2 + np_1 + C_0. \quad (17)$$

The loss of the manufacturer is the lowest when the moral risk-taking behaviours of offline channel retailers are discovered through supervising their activities:

$$U_0(p_1) \leq a_2 - a_1 + np_1 + C_0, \\ U_0(p_1) = \frac{u_2}{p_1} - \frac{(1-p_1)}{p_1^2} u_2 + np_1 + C_0. \quad (18)$$

According to the above equation, the minimum value that can be calculated when the first-order derivative $U_0'(p_1)$ is taken and set to 0. Then, $np_1^3 - 2u_2 p_1 + 2u_2 = 0$, which certifies that $p_1$ exists and makes the failure cost of the core subjects participating in the integration of dual-channel supply chain become smaller than $U(p_1)$.

This condition indicates that setting a maximum punishment amount limit for the moral risks of retailers can lower the success rate of moral risk-taking behaviours of retailers, enhance the internal supervision mechanism during the integration process of the dual-channel supply chain, and facilitate the exchange mechanism between integrative subjects.

## 4. CONCLUSIONS

When a LED lighting product manufacturer adopts the dual-channel direct sale strategy, its investment in supply chain information system integration is in a market contract form. Information is integrated into the dual-channel marketing process to make offline retailers and the manufacturer jointly participate in value creation activities and form a technical contract. The collaborative effect generated by enterprises, participating in information system integration, generates the spill over effect for other enterprises and motivates them to participate in the integration of the supply chain information system.

For further effective prevention, control and constraint of moral risks during the dual-channel marketing process of LED lighting products, three steps are recommended. First, starting from the roots of moral risks, control of the internal information asymmetry phenomenon of the supply chain should be enhanced to improve the enthusiasm of integrative subjects for participating in information integration. Second, prevention and control of moral risks should be intensified by establishing an effective monitoring organization and setting up relevant punishment regulations on violation and punishment amount. Finally, enterprises with poor operating capabilities can be "knocked out" by establishing a knockout/constraint mechanism of enterprises through performance appraisal to enhance the overall competitiveness of the entire supply chain, improve the overall operating efficiency, and motivate enterprises to participate actively in the collaborative operation.

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# PATENT MAP ANALYSIS OF CHINA'S ORGANIC LIGHT-EMITTING DIODE TECHNOLOGY

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**ABSTRACT**

This study is to explore the traits of research and development of China's Organic Light-emitting Diode (OLED) technology through the analysis of patent applications, applicant information and patent distribution in the OLED field. Using a sample of 8366 patent data, a statistical analysis as well as the patent map was employed to identify the technology life cycle, major OLED enterprises patent layout and key development fields of OLED technology in China. The result indicates that China's enterprises could develop an OLED technology that is oriented toward safety and emergency management applications in the future. Patent analysis based on the patent map of China's OLED technology is conducive to the understanding of the competitive situation in China's OLED industry, discovering the development direction of OLED technology, and providing enterprises with theoretical guidance in patent layout and strategic planning.

**Keywords:** OLED patent map, statistical analysis, clustering analysis, China

## 1. INTRODUCTION

Organic light-emitting diode (OLED) has advantages of high luminance, high efficiency, independent light-emitting feature, simple craftsmanship, and quick response [1–3]. OLED has the largest potential in the energy efficient lighting application field [4, 5]. The development of OLED creates a new profit growth source in the display and lighting fields. OLED originated from Europe but achieved large-scale industrialization mainly in East Asian countries, such as Korea and Japan. On the one hand, China is a large target market for industrializing OLED technology and possesses great consumption potentials, thereby, attracting significant attention from the product research and development (R&D), production and marketing of related enterprises globally. On the other hand, Chinese enterprises are actively engaged in the R&D, production, and utilization of the OLED technology [6] and have become important players in the global OLED market through gradual development.

Patent map, as a visualization method of patent analysis, can reflect patent information efficiently, and plays increasingly important role in creating competitive strategy for enterprise decision-making and government policy-formulation [7, 8]. For enterprises, the establishment of a patent map has two main meanings. The passive perspective prevents the design of an identity with patents from others. The positive perspective creates new patents actively in the competitive environment [9]. Furthermore, a patent map can be used to measure technological distance [10], discover technological gaps [11], analyse market competitiveness and facilitate the strategic planning of enterprises. Therefore, many scholars have studied methods to construct and analyse patent maps. Based on machine learning and analy-

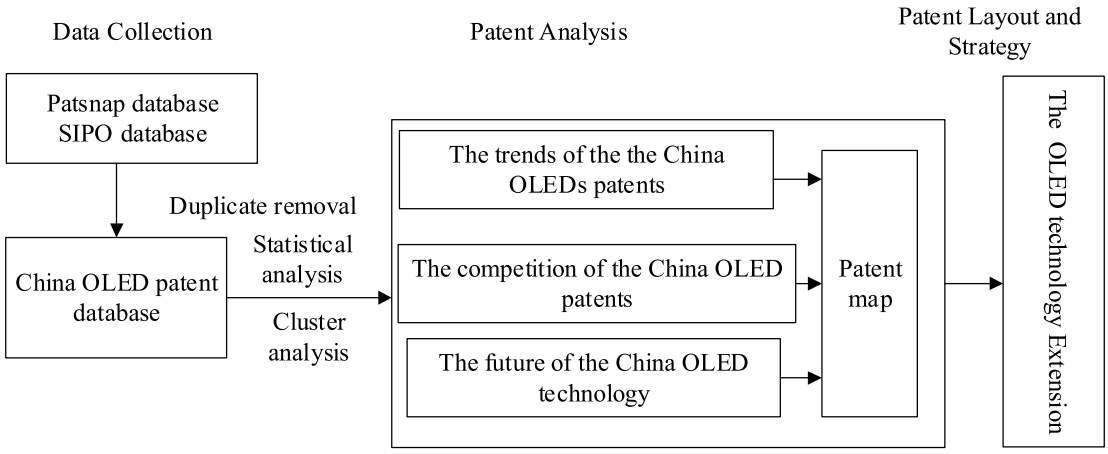


Fig. 1. Research direction

sis of industrial patents, Suominen constructed an industrial patent map [12]. On the basis of 74 patent samples from the American automobile industry in 2005–2007, Chen invited 10 senior patent examiners and 29 designers from the automobile industry to construct a patent map [9]. Honghua formed a semantic network and built a patent map through the K-mean clustering algorithm using structural and non-structural projects included in the patent literature [13]. According to text mining, principal component analysis and patent vacancies definition, Lee proposed a method to create and utilize keyword-based patent maps for use in new technology creation activity [11]. Yoon analysed patent data based on semantic analysis and constructed a dynamic patent map by creating a subject–action–object method to determine competitive schemes for R&D plans of enterprises [14]. In [15] authors proposed a generative topographic mapping method and discovered a technological gap on the basis of a patent map. There are no unanimous methods of patent map design yet, although scholars have made every possible effort to design a patent map. It is creative to design and utilize the patent map [9].

In this study, the development direction of China's OLED patent is analysed based on relevant data. The development trend of China's OLED technology is reflected in the patent map.

## 2. DATA SOURCE AND RESEARCH METHODS

### 2.1. Data source

Patent data was collected on April 10, 2017 from PatSnap and the database of the State Intellectual Property Office of the P. R. of China from 1996 to 2017. After the "de-noising and de- weighting" processing of the acquired data, 8,366 data on OLED patents in China was collected and used to establish a patent database for patent analysis.

### 2.2. Research method

The research is mainly comprised of data collection, patent analysis, and patent layout, Fig. 1. Patent map analysis of China's OLED technology is divided into the development trend, regional competition, and development direction analyses of China's OLED technology. A patent map of China's OLED technology is constructed based on the statistical and clustering analyses. A possible direction of China's OLED technology extension is analysed based on the patent map, which provides references to the patent layout and strategic planning of Chinese enterprises.

## 3. PATENT ANALYSIS

### 3.1. Development trend analysis of China's OLED technology

*1. Temporal distribution and trend of OLED patent application quantity in China*

Time-based statistics is used for OLED patent applications in China. The temporal distribution and the trend map of OLED patent applications are shown in Fig 2.

In Fig 2, there are no relevant patent applications of the OLED technology prior to 2001, but OLED patent applications increased gradually from 2001 to 2008. The quantity of OLED patent applications reached 300 in 2005, and kept at approximately 300

**Table 1. Region ranking in terms of OLED patent quantities in China**

| Province | Guang-dong | Beijing | Jiangsu | Shanghai | Sichuan | Shanxi | Hubei | Jilin | Shandong | Anhui |
|---|---|---|---|---|---|---|---|---|---|---|
| OLED patent quantity | 899 | 787 | 779 | 492 | 350 | 147 | 112 | 109 | 106 | 78 |

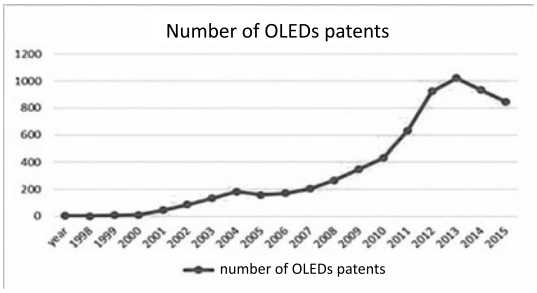


Fig 2. Temporal distribution and trend of OLED patent applications in China

in the next three years. The OLED technology has been experiencing rapid development since 2008, especially in 2012 and 2013. The quantity of OLED patent applications began to decrease since 2014. The development of China's OLED technology mainly includes the germination stage (before 2008) and the development stage (from 2009 onward).

*2. Regional development of China's OLED technology*

The regional ranking of the OLED patent quantity in China is listed in Table 1. Guangdong, Beijing, Shanghai, and Sichuan have large OLED patent application quantities. On the one hand, the regional development of China's OLED technology is closely related to the regional economic development level. Generally, regions with high economic development levels have high OLED technology development levels. On the other hand, the number of regional research organizations is also related with the OLED technological level. Regions in China with high quantities of OLED patents also have abundant universities and scientific research institutes.

### 3.2. Regional competition analysis of China's OLED technology

*1. OLED patent applicant ranking in China*

According to the ranking of major OLED patent applicants in China, Table 2 shows that the BOE Group has the largest number of OLED patent applications, followed by the Sichuan CCO Corporation, Shenzhen China Star Optoelectronics Technology (CSOT), LG Display Co., Ltd, and Samsung Display Co., Ltd. These companies have more than 200 OLED patents, and most of the OLED patents were for display screen and other related products.

Among the top 10 applicants, only one is a university, i.e. Tsinghua University (THU). Beijing Visionox Science and Technology Co., Ltd. is a high-tech enterprise founded by THU and other investors.

**Table 2. OLED patent applicant ranking in China**

| Patents Applicants (Owners) | Numbers | Ranking | Patents Applicants (Owners) | Numbers | Ranking |
|---|---|---|---|---|---|
| BOE Technology Group Co., Ltd. | 621 | 1 | EverDisplay Optronics Limited | 167 | 6 |
| Sichuan CCO Display Technology Co., Ltd (CCO) | 263 | 2 | Visionox Technology Co., Ltd | 166 | 7 |
| Shenzhen China Star Optoelectronics Technology Co., Ltd (CSOT) | 249 | 3 | Guo Display Optoelectronics Technology Co., Ltd(GVO) | 123 | 8 |
| LG Display Co., Ltd | 209 | 4 | Tsinghua University | 120 | 9 |
| Samsung Display Co., Ltd | 207 | 5 | Kunshan Visionox Display Technology Co., Ltd | 116 | 10 |

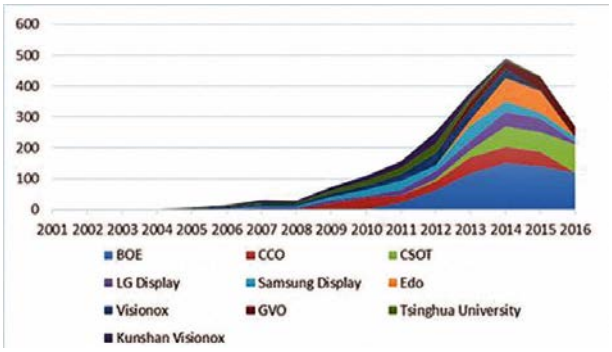


Fig 3. R&D trend of OLED patent applicants in China

This enterprise mainly engaged in the development, production and marketing of OLED as well as new display products. Kunshan GVO Corporation, which was founded in 2012, is a major executor of AMOLED industrialization projects. Kunshan Visionox Science and Technology Co., Ltd. is a subsidiary company of Visionox Science and Technology Co., Ltd.

The ranking of the OLED patent applicants reflects the fierce market competition in China. BOE Group and Beijing Visionox Science and Technology Co., Ltd. and affiliated companies possess distinct advantages.

*2. R&D trend of the OLED patent applicants in China*

The OLED market in China shows fierce competition according to analysis of R&D trend of OLED applicants (patents) in China, Fig. 3. THU and Beijing Visionox Science and Technology Co., Ltd. through their OLED project teams were the first ones to make progress and apply patents for OLED technology. They introduced the OLED technology R&D and patent layout and founded two subsidiary companies, which made significant progress in the OLED technology after 2008.

LG Display Co., Ltd. of Korea lags THU in terms of patent layout in China and maintains a stable growth. It applied for the most of OLED patents in 2014–2015 that is approximately 45 patents per year. Samsung Display Co., Ltd. started its OLED patent layout in China in 2006.

BOE Group, a Chinese enterprise, started its patent layout later, but this enterprise developed quickly and achieved breakthrough growths in terms of patent applications from 2013 to 2016, showing an annual number of nearly 130. Sichuan CCO Corporation began to develop quickly after 2008 and achieved the quickest development in 2013–2015.

### 3.3. Development direction of China's OLED technology

*1. Key OLED technologies in China*

The OLED industry key technologies can be identified from applying statistics on the International Patent Classification (IPC) category of China's OLED patents and on the IPC category with additional patent features.

The technologies represented by the IPC categories and related IPC classification numbers in Table 3 are as follows. H01L27/32: components for the exclusive use for light emission, such as flat-panel displays using OLED; H01L51/52: parts of devices; H01L51/56: special methods or equipment to manufacture or process these devices or parts; H01L51/50: devices for the exclusive use for light emission, such as OLED or polymeric light-emitting diodes (PLED) (organic semiconductor laser unit is enlisted in H01S5/36); G09G3/32: semiconductors, such as light-emitting diodes; H01L51/54: material selection; C09K11/06: organic light-emitting materials; G09F9/33: semiconductor devices (e.g., diodes); H01L51/00: solid devices that use active parts of organic materials or combine organic and other materials as the active part; special techniques or devices to manufacture or process these devices or parts; H05B33/14: devices composed of or configured with chemical or physical components of electroluminescent materials. On the basis of the ranking of the IPC classification numbers of China's OLED technologies, H01L27/32 and H01L51/50 are the main technologies. OLED technologies mainly contain technologies for displays and related products.

**Table 3. Major IPC categories of China's OLED patents and their corresponding quantities**

| **IPC classification** | **H01L27/32** | **H01L51/52** | **H01L51/56** | **H01L51/50** | **G09G3/32** |
|---|---|---|---|---|---|
| Number of patents | 1,479 | 1,435 | 1,206 | 893 | 720 |
| **IPC classification** | **H01L51/54** | **C09K11/06** | **G09F9/33** | **H01L51/00** | **H05B33/14** |
| Number of patents | 679 | 474 | 236 | 227 | 183 |

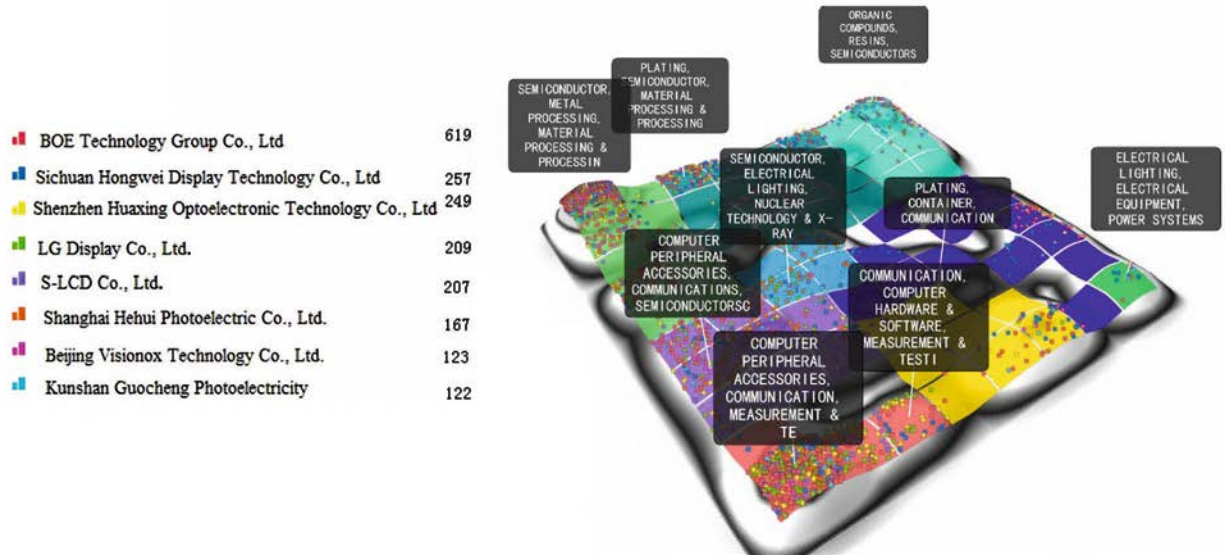


Fig 4. Clustering patent map of China's OLED technologies

*2. Clustering patent map of China's OLED technologies*

An OLED patent map, Fig. 4, was constructed through the clustering analysis of high-quality patents based on PatSnap. In the patent map, a high contour line represents more technical patents and the high maturity of this technology. According to the clustering patent map analysis of China's OLED technologies, most OLED patents are related to the semiconductor, coating, and metal processing technologies, and are applied by many companies, indicating that these technologies are relatively mature, and a fierce competition exists among the enterprises of the same type. Patents for computer accessories, tests, and communication rank second in terms of quantity and high layout density. Although there are many patents on organic compounds, resin and semiconductor technologies, only a few applicants, mainly including the BOE Group and Beijing Visionox Science and Technology Co., Ltd., are identified. This scenario shows that the BOE Group and Beijing Visionox Science and Technology Co., Ltd. possess advantages in these technologies. Electrical lighting, electrical equipment and dynamical systems have few patents, resulting in low contour lines and a few layout enterprises in the patent map. These technologies have "big rooms" for development and a technological "blue sea".

The screening of invalid patents and patent transfer revealed that the BOE Group, Sichuan CCO Corporation, Shenzhen CSOT, LG Display Co., Ltd., and Samsung Display Co., Ltd. currently hold the greatest part of such patents. The top eight companies have been marked in different colours in Fig. 4 that reflect their market shares in different key fields and the overall layout.

### 3.4. Key development field of China's OLED industry oriented for safety and emergency management in the future

The clustering patent map analysis of China's OLED technologies reveals that OLED technologies have driven the development of many related industries and produced new profit growth points, such as computer accessories and hardware. Meanwhile, OLED technologies encourage enterprises in the "blue sea" in China's OLED patent layout, such as electrical lighting, electrical equipment and dynamical systems, to determine the relevant patent layout and adjust their technological development. The application of OLED technology to safety and emergency management, including public emergency management, public safety protection and personal safety management, is an important direction. [16–18] Particular attention should be given to the development of the OLED technology for the early warning and prevention of crowd stampede.

Safety is one of the most basic demands of human beings. The application of the OLED technology in the safety management field is not only brought about by the demand of technological extension but also by the market demand, Fig. 5. In public emergency management, the evacuation indicator screen for public emergency will be designed

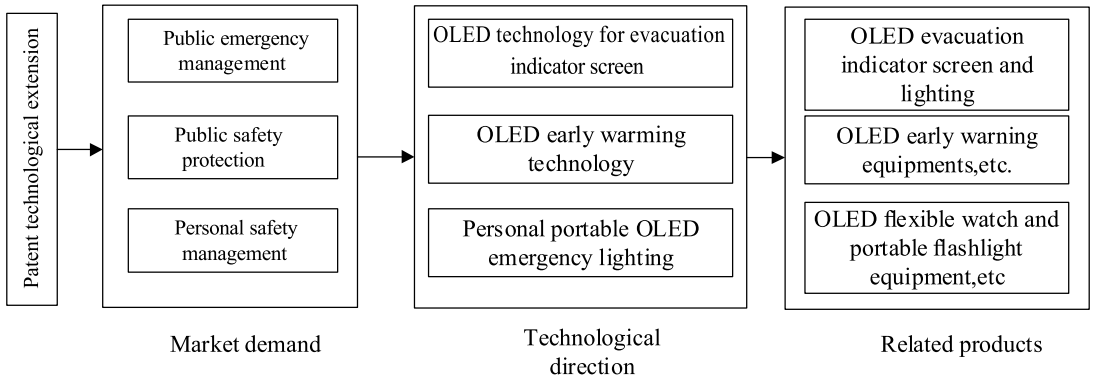


Fig 5. OLED technological development direction in the safety and emergency management field in China

using the OLED technology and can achieve the energy-efficiency goal. In public safety protection, the OLED early warning technology shall be improved and OLED early warning equipment shall be designed. In personal safety management, OLED flexible watches and portable flashlights are designed by optimizing personal portable emergency lighting OLED technologies.

## 4. CONCLUSIONS

A patent map of China's OLED technology was constructed based on the related development trend, competition situation, and development direction analyses. The following conclusions were drawn.

First, the lifecycle of China's OLED technology is divided into the germination, development, mature, and recession stages. China's OLED technologies have entered the development stage from the germination stage through years of development and are currently being improved gradually.

Second, THU and affiliated companies were the first enterprises that engaged in the OLED patent layout and possess certain advantages due to several years' development. There are other OLED enterprises in China which develop quickly. For example, the BOE Group grows rapidly and possesses some technological advantages despite of starting late.

Third, China's OLED technologies focus on semiconductors, coating, metal processing, computer accessories and testing, and fierce market competition exist in these areas. Enterprises can cooperate by maximizing the use of existing technologies to realize win–win situations. They can also innovate vigorously, and explore the technological "blue sea".

Finally, the development direction of China's OLED technologies in safety and emergency management is proposed based on the OLED patent analysis and market demands in China.

Specifically, the patent map analysis of China's OLED technologies is beneficial to understanding the development of China's OLED industry and analysing the key layout and the blank fields. However, this study has some limitations, such as the absence of empirical analysis of the further development of China's OLED technologies. These problems remain to be discussed in future studies.

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# RESEARCH ON THE EVALUATION OF GROWTH QUALITY OF LISTED LED COMPANIES

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**ABSTRACT**

The growth quality of listed LED companies determines the competitiveness of the LED industry. Based on the industrial innovation theory, corporate governance theory and enterprise organization theory, this paper constructs a growth quality model of listed LED companies. This model is composed of operation capacity, innovation quality and governance level, as the three dimensions. Then, it selects 24 Chinese listed LED companies, using the combination weighting method and matrix method to evaluate their growth quality. Through a comparative analysis of the top three enterprises and the last three enterprises, it verifies the scientificity of the index system, and puts forward feasible promotion suggestions for the enterprise combined with indexes and results. The growth quality evaluation system of listed LED companies not only can provide an effective analysis method for investment institutions, but also can provide a scientific self-checking tool for listed LED companies.

**Keywords:** LED industry, listed company, evaluation of growth quality

## 1. INTRODUCTION

Optoelectronics device is the core of the photoelectron information technologies. With the development of Chinese social economy, the scale of LED equipment industry is gradually expanding. In 2016, the revenue scale of Chinese LED equipment market reached 521 billion 600 million yuan, and the gap between Chinese photoelectron industry and that of the developed countries is narrowing. As the industry leading enterprises, listed companies improve their development ability through financing and allocating resources. As the same time, by independent innovation, endogenous accumulation, market competitiveness and social influence, they have also become the most dynamic micro subject that drive industry development. So, the growth quality of listed LED companies has become an important factor affecting the development of the LED industry. There are many factors that affect the growth quality of listed companies. Kakati [1] thinks that the enterprise strategy, management ability and entrepreneurs qualification are important factors that affect the growth of enterprises. Simon et al. [2] find that the more incentives for management, the more opportunities for companies' growth. In the study of factors that affect the growth of enterprises, Aivazian [3] finds that the higher the proportion of long-term debt in the total debt is, the more growth opportunities companies get. Adan [4] investigates the influence of the investment environment on enterprise growth quality. Kang [5] believes that government policy is important for the growth of enterprises. Rzepka [6] and Wawrzynek [7] believe that the influence of organizational network on enterprise growth is greater. Yun J.J. and Park K. [8] demonstrated that entrepreneurial capabilities and social networks have important implications for business growth. Amir et al. [9] investigated the influence mechanism of cost management on enterprise growth. Wei [10] constructs an index system of the growth of listed companies, including per-capita output value, R&D expenditure, total as-

sets, main business income, gross profit, industrial sales, and energy consumption per unit of output value, foreign direct investments, export delivery value, R&D personnel equivalent, and effective patent number. Similarly, Yang [11] constructs an index system including production factors, demand conditions, market structure, four government aspects of primary indexes, and a number of enterprises, gross industrial output value, total assets, average number of employees, industrial sales value, export delivery value, market share, value-added tax, total pre-tax projects and other 9 level secondary indexes. Combined with characteristics of the LED industry and stock market, this paper constructs an evaluation system of the growth quality of listed LED companies, and provides reference for the research on growth quality of the companies.

## 2. MODEL DESIGN

### 2.1. Evaluation index system of growth quality of listed LED companies

Based on the research results of scholars, and combined with the industry innovation theory, corporate governance theory and enterprise organization theory, we find that the growth quality of listed LED companies is composed of innovation quality, governance level and operation capacity, Fig. 1.

*1. Innovation Quality*

Innovation is the key factor that improves the core competitiveness of enterprises. For listed LED companies, innovation can improve the productivity of listed companies and expand their market share, so that they can maintain sustainable development. In this paper, we evaluate the innovation quality of listed LED companies from two aspects: the innovation input and the innovation output. In terms of innovation input, given two aspects of talent and capital, we select innovative talent input level, innovation capital input level and innovation capital input intensity as the three indicators. The core indicator of innovation output is the number of patent applications. For listed LED companies, an invention patent that can improve the product and method is more significant compared to the utility model patent and industrial design patent. So we choose the index of high quality invention patent number. At the same time, intangible asset is also an important innovation output of listed companies. The direct innovation benefit of listed companies cannot

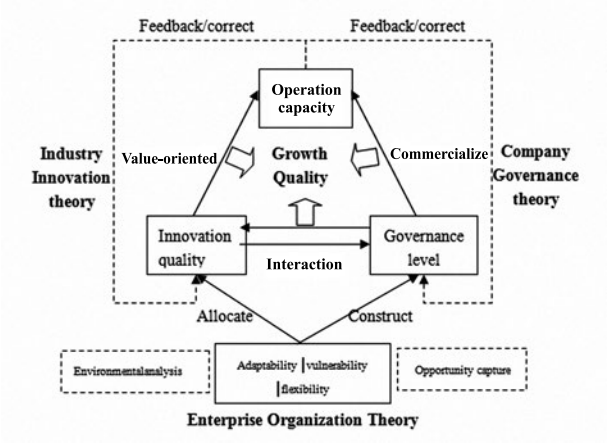


Fig 1. A three-dimensional model of the connotation of listed LED companies' growth quality

be separated from other benefits. And the most direct reflection of the innovation benefit is the technology market turnover and the output value of new products, but in the same statistical calibre, they cannot be reflected in the company's annual financial report. There is great relevance between the productivity of labour and the output of the innovation benefit. The use of new techniques, new materials and new processes can improve the productivity of the company. So we use the productivity of labour to substitute the innovation benefit output.

*2. Governance Level*

Listed companies are the leaders of the LED industry, and they need to face the public and shareholders. Listed companies have their own pursuit of interests, but they also have the appeal of social responsibility. So, only the reasonable governance level can achieve the continuous development of the company. The corporate governance research centre of the Chinese Academy of Social Sciences proposes that the corporate governance capability usually includes the rights and responsibilities of the board of directors and stakeholders, information disclosure, social responsibility and other dimensions. On this basis, given the importance of the shareholding structure of listed companies, and availability and comparability of data, we choose the secondary indicators including internal structure, information disclosure and social responsibility as the three aspects to evaluate the dimension of governance level of listed LED companies' growth quality. The internal structure is reflected from two aspects of ownership concentration and centralization of decision-making power. The timeliness and authenticity of information disclosure can reflect

the level of information disclosure. And the evaluation of social responsibility is mainly done from two aspects of social employment contribution and social economic contribution.

*3. Operation Capacity*

For listed companies, the function of the operation is to make product, and the financial index is the best embodiment of the operation level. In this paper, we select the level of shareholder's income, the level of sales revenue and earnings stability as the three indicators to measure the difference in profitability of listed LED companies. In the aspect of solvency, we choose a reasonable level of debt, long-term debt paying ability and short-term debt paying ability to distinguish the difference in solvency of listed LED companies. Turnover refers to the ability that enterprise uses various assets to make profit. We choose current assets turnover capacity and noncurrent assets turnover capacity to measure it. The growth ability of a listed LED company directly reflects the trend and speed of the future development of the company. So we select the growth rate of gross assets, the growth rate of operating income, profit growth rate and other indicators. At the same time, we also select equity value growth ability (EVA) and market premium ability (MVA) to show the growth feature of the company in the context of value creation.

### 2.2. Model design

*1. Primitive matrix construction*

If there are $m$ listed LED companies, and each listed company has $n$ evaluation indicators, we can build a primitive matrix as:

$$X = \begin{bmatrix} x_1(1) & x_2(1) & \cdots & x_m(1) \\ x_1(2) & x_2(2) & \cdots & x_m(2) \\ \vdots & \vdots & & \vdots \\ x_1(n) & x_2(n) & \cdots & x_m(n) \end{bmatrix}. \quad (1)$$

*2. Standardization*

The measurement unit of each index is different, and the comprehensive calculation of the index is greatly affected by the dimension, so, we should eliminate the dimension and standardize index values.

Let J+ = {Benefit index}, J- = {Cost index}.

Then,

$$x'_k(i) = \frac{x_k(i) - \min x_k(i)}{\max x_k(i) - \min x_k(i)} \times \times 0.4 + 0.6, (k \in J^+), \quad (2)$$

$$x'_k(i) = \frac{\max x_k(i) - x_k(i)}{\max x_k(i) - \min x_k(i)} \times \times 0.4 + 0.6, (k \in J^-), \quad (3)$$

and $X'$ is standardized as:

$$X' = \begin{bmatrix} x'_1(1) & x'_2(1) & \cdots & x'_m(1) \\ x'_1(2) & x'_2(2) & \cdots & x'_m(2) \\ \vdots & \vdots & & \vdots \\ x'_1(n) & x'_2(n) & \cdots & x'_m(n) \end{bmatrix}. \quad (4)$$

*3. Weight determination*

In this paper, we use the contrast summation scoring method and the entropy method to implement additive combination weighting, which makes up for the deficiency of subjective weight and objective weight.

*Contrast summation scoring method*

The contrast summation scoring method can be divided into various types. In this paper, we choose a 0–1 scoring method. Each index is compared and scored one by one, and the sum of the scores is the weight of this index. Finally, the corresponding weight value is obtained by normalization. Among them, we set that the weight $r_{ij}$ can only be 0, 1 or 0.5. When the function of $i$ index is higher than that of the $j$ index, $r_{ij} = 1$, and the corresponding $r_{ji} = 0$, and if the function of $i$ index matches the function of $j$ index, then $r_{ij} = r_{ji} = 0.5$.

So, the weight of the $i$ index is:

$$\omega_i' = \sum_{j=1}^{n} r_{ij} \Big/ \sum_{i=1}^{n}\sum_{j=1}^{n} r_{ij}. \quad (5)$$

Normalizing in turn, we can obtain the corresponding index weight.

*Entropy method*

In information theory, entropy is a measure of uncertainty, and the greater the amount of information, the smaller the uncertainty and the smaller the entropy. On the contrary, is the smaller the amount of information, the greater the uncertainty and the greater the entropy. Entropy method deter-

mines weight on the basis of the differences between index data, and the basic approach is as follows:

– The first step: calculate the proportion $P_k(i)$ of $i$ index of listed LED companies:

$$P_k(i) = \frac{x'_k(i)}{\sum_{k=1}^{m} x'_k(i)}, (k = 1,2,\cdots,m, i = 1,2,\cdots,n). \quad (6)$$

– The second step: calculate the entropy $e_i$ of $i$ index:

$$e_i = -(\ln m)^{-1} \sum_{i=1}^{m} (p_k(i) \ln p_k(i)), (i = 1,2,\cdots,n). \quad (7)$$

– The third step: calculate the otherness coefficient $d_i$ of $i$ index:

$$d_i = 1 - e_i, (i = 1,2,\cdots,n). \quad (8)$$

– The fourth step: calculate the weight coefficient $\omega''_i$ of $i$ index:

$$\omega''_i = \frac{d_i}{\sum_{i=1}^{n} d_i}. \quad (9)$$

According to the additivity of the entropy, normalized by (9), the weight of the upper indexes can be obtained.

*Combination weighting*

There are two forms of combination weighting: multiplicative weighting and additive weighting. In order to operate simply and conveniently, this paper adopts the method of additive combination weighting:

$$\omega_i = \lambda \omega'_i + (1 - \lambda)\omega''_i. \quad (10)$$

Among them, $\lambda$ is the weighted proportion, and it usually is set to 0.5.

*4. The listed companies growth quality calculation*

According to different importance of evaluation indexes, multiplying the index standard matrix by the weight matrix, we can get the final growth quality matrix of listed LED companies. In order to meet the needs of normal observation, final results are all transformed into a centesimal system.

### 2.3. Measurement of the growth quality of listed LED companies

*1. Measurement object selection*

This paper selects the largest Chinese capital market, that is, the A-share market. By the end of March 2017, it included a total of 3175 companies. Among them are 24 listed LED companies: *Mu-Linsen (MLS), Abison Sen (ABS), Hua-Chan-optoelectronics (HC), Jia Wei shares (WJ), Chang Fang group (CF), Ju Fei optoelectronics (JF), Wan Run technologies (WR), Qin Shang optoelectronics (QS), Rui Feng optoelectronics (RF), Ao Tuo Electronics (AT), Hong Li zhihui (HL), Lei man shares (LM), Qian Zhao optoelectronics (QZ), Ou Feiguang (OYG), Guo Xing optoelectronics (GX), Shui-Jin goptoelectronics (SJ), Li Da optoelectronics (LD), Lian Chuang Electronics (LCE), De Hao Runda (DH), Guang Dian shares (GD), Lian Chuang optoelectronics (LCO), Le Kai Film (LK), Feng Huang Optics (FH) and San An Optoelectronics (SA).*

*2. Data source*

According to the evaluation index system of the growth quality of Chinese listed LED companies, based on the original data of listed companies in the wind database, annual reports of listed companies, Chinese patent database and other related databases, following the operation steps of growth quality evaluation method in order to evaluate the growth quality of Chinese listed LED companies, we obtain the growth quality score of listed LED companies.

*3.Weight calculation*

According to (1) – (10) and using the Matlab7.0 software, we calculated weight coefficients of the growth quality evaluation index system of listed LED companies, Table 1.

Weight coefficients of each level evaluation index were determined by the combination weighting method. The weights of innovation quality, governance level and operation capacity are 0.319, 0.172 and 0.509 respectively. The weight of the operation capacity is the largest in three dimensions, and the growth ability composed of growth rate of gross assets, growth rate of operating income, profit growth rate, equity value growth ability and market premium ability accounts for nearly 0.435 of the weight in the dimension of the operation capacity.

**Table 1. Comprehensive weights of evaluation indexes for each level of listed LED companies**

| **Target** | **Innovation quality B1** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weight | First: 0.319 | | | | | | | | | | | | |
| Sub criterion layer | Innovation input C1 | | | Innovation output C2 | | | | | | | | | |
| Weight | 0.397 | | | 0.603 | | | | | | | | | |
| Scheme layer | D1 | D2 | | D3 | D4 | | | D5 | | D6 | | D7 | |
| Weight | 0.347 | 0.353 | | 0.300 | 0.266 | | | 0.273 | | 0.236 | | 0.226 | |
| Target | Governance level B2 | | | | | | | | | | | | |
| Weight | Second: 0.172 | | | | | | | | | | | | |
| Sub criterion layer | Internal structure C3 | | | Information disclosure C4 | | | | Social responsibility C5 | | | | | |
| Weight | 0.248 | | | 0.292 | | | | 0.461 | | | | | |
| Scheme layer | D8 | D9 | | D10 | | | D11 | D12 | | | D13 | | |
| Weight | 0.659 | 0.341 | | 0.279 | | | 0.721 | 0.450 | | | 0.550 | | |
| Target | Operation capacity B3 | | | | | | | | | | | | |
| Weight | Third: 0.509 | | | | | | | | | | | | |
| Sub criterion layer | Profitability C6 | | | Solvency C7 | | | Turnover C8 | | Growth ability C9 | | | | |
| Weight | 0.267 | | | 0.207 | | | 0.091 | | 0.435 | | | | |
| Scheme layer | D14 | D15 | D16 | D17 | D18 | D19 | D20 | D21 | D22 | D23 | D24 | D25 | D26 |
| Weight | 0.391 | 0.363 | 0.246 | 0.467 | 0.274 | 0.259 | 0.5 | 0.5 | 0.167 | 0.173 | 0.191 | 0.24 | 0.229 |

It fully reflects that the function of listed companies is assessed by continuous profitability, in line with the anticipation judgment of the market on the growth quality of listed companies. The innovation quality is the core of growth quality of sci-tech listed companies, and its weight reaches 0.319. The weight of innovation output (0.603) is higher than the weight of innovation input (0.397), which reflects the principle of innovation priority and balancing benefit of listed LED companies. The weight of governance level is small, only 0.172, but as the listed company level of governance reflects the company's image, it is the basis of the growth quality of the enterprise.

## 3. RESULTS ANALYSIS AND DISCUSSION

### 3.1. The analysis of operation capacity

In the dimension of operation capacity, the three most competitive enterprises are respectively *WJ (*85.83), *LCE(*82.17) and *HL(*81.14), and the relative ranking of the last three companies are: 71.2 (*LM)*, 70.9 (*DH*) and 68.98 (*QZ)*. And for the top three enterprises, outstanding performance of *WJ* in operating capacity largely depends on its growth rate of operating income, profit growth rate, and growth rate of gross assets, reaching 179.68, 1246.1 and 367.825 % respectively. In 2015, this company completed a major reorganization of assets and achieved the integration of the upstream photoelectron industry. The ROE of *HL* and *LCE* are more than 15 %, which is far higher than the industry average level (6.2178 %), and their net sales rate is over 10 %, that is larger than the industry average (6 %). For the last three enterprises, the asset-liability ratios of *LM, DH* and *QZ* are generally more than 70 %, ROE is less than 1 %, and operating profit growth rate is negative. The output value of the LED industry is improving in 2015. However, the fierce competition leads to the decline in product price, and some listed companies with poor cost control drop in a sharp decline in net profit.

### 3.2. The analysis of innovation quality

In the dimension of innovation quality, the top three enterprises are *SA (*81.24), *OYG (*76.79) and *DH (*73.35), and the last three enterprises are *MLS (*64.96), *LCO (*63.67) and *FH (*61.53). *SA* and *OYG* are outstanding in innovation input. Their technical personnel proportion in the total number is more than 14 %, R&D input intensity is more than 5 %. The R&D input of *OYG* is 950 million yuan, *SA* invests 340 million yuan. *OYG* owns 172 patents and *SA* owns 94 patents. The high R&D input brings *OYG* the leading technology in the field of precision optoelectronics film components and the top one shipment in global infrared cut-off filters. Although the R&D input intensity of *DH* is less than *SA* and *OYG* intensities, its intangible assets output index is better. For the last three enterprises, their R&D inputs restrict enterprises' innovation ability. The R&D input intensities of *MLS, LCO* and *FH* are less than 3 %, and their technical personnel occupation ratios are less than 5 %. It belongs to the phenomenon that low input results in lower R&D output. The patents of *LCO* and *FH* are 0, and the average proportion of intangible assets is 0.01 %, that is much lower than the industry average level (0.03 %).

### 3.3. The analysis of governance level

The difference value of governance level between corporates is the largest, reaching 27.2, thus reflecting that the governance normalization and social responsibility of listed companied should be strengthened. For the outstanding corporate, such as *FH (*92.73), proportion of floating stock reaches 100 %, and the annual report disclosure timeliness is far more than in case of other enterprises. For the poor performance corporate, such as *ABS (*65.53), proportion of floating stock is only 28.49 %, the disclosure timeliness of the annual report is poor, the chairman and the general manager is the same person, and its modern corporate governance mechanism is not perfect yet.

### 3.4 The analysis of growth quality

Enterprises with higher comprehensive growth quality are *SA*, *WJ* and *OYG*. The innovation quality and governance level is *SA'*s advantage field, showing a comprehensive leading technology advantage in the industry, but its operation capacity is relatively a short board, showing a phenomenon of low scale growth and high profit. And its growth rate of operating income is 6.08 % that is far below then the average industry level (22.47 %), while indexes of sales net profit rate and operating profit growth rate perform well, being, respectively, 12.44 and 12.94 %. If *SA* wants to achieve long development, it should take advantage of the technology superiority of subdivision domain to carry out its business along the industrial chain, and expand its business space. The three dimensions of *OYG* are more balanced. It's operating capacity ranks fourth, the ability to innovate is second, governance capacity ranks the second place, and the future growth space of enterprise is large. *WJ* performs well in operation capacity, ranking first, but its innovation ability and governance level only rank sixteenth and fifteenth, showing significant short-term economic benefits. However, to maintain sustained growth, the corporate also needs to strengthen the core of long-term development, improve the innovation ability, and regulate corporate governance structure.

## 4 CONCLUSIONS

The LED industry is called the first leading industry in the twenty-first century, and is the most competitive industry of Chinese high-tech industry in the world as well. The growth quality of the listed LED companies determines the future competition potential of Chinese LED industry. This paper constructs the "three-dimensional" evaluation model of photoelectron listed companies to analyse the growth quality of 24 listed LED companies. The main conclusions are as follows:

– There are significant differences in the growth quality of listed LED companies. The scores of 24 listed LED companies are from 69.34 to 81.59, the score distribution is significantly different, showing the characteristics of the middle intensive. The score of companies over 80 have only *SA* and *OFG*, below 70 points – only *LM* and *QZ*. This correlation score is in line with the companies' annual operation aspect in 2015, fully verifying the scientific content of the index system, and can be applied to analyse the investment of listed LED companies.

– Reasons for different scores of listed companies in main dimensions are widely different. Although the comprehensive growth quality score of *SA* is the top one, it mainly relies on outstand-

ing performance in innovation quality and governance level, having short board in operation capacity. *WF* is on the contrary, its comprehensive growth quality score ranks third, and it mainly depends on the high-quality performance in operation capacity, and the short board phenomenon in innovation quality and governance level is serious. To maintain a healthy development, it needs to continue to exploit its advantages, and make up for the short board. The "three dimensional" model of growth quality of listed LED companies has a great application value for the enterprise to define advantages and make up for the short board.

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# RESEARCH AND IMPROVEMENT OF FLEXIBLE LUMINOUS PANEL MOST IMPORTANT PARAMETERS

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**ABSTRACT**

The factors determining the luminance of electroluminescent panels (ELPs) are formulated. It is indicated that luminance could be increased by the modernization of the dielectric composition of the binder used in the preparation of phosphor slurry for emitting layer. The ways of improving the durability of the radiating structures are demonstrated. Based on the results of research ELPs were manufactured and their luminance and temporal characteristics were measured.

**Keywords**: electroluminescent panel, luminance, durability, phosphors, dielectric permeability, electric field, the synthesis of the dielectric binder of hydroxyl and carbonate groups

## 1. INTRODUCTION

ELPs, which are flat flexible generators of optical radiation, are widely used as effective local light sources in various measuring devices, as main components of signal and emergency lighting products, as well as most important elements of advertising and decorative light panels of different dimensions.

ELP main characteristics are:

– Power supply voltage, $U$: 40 ÷ 500 V;

– Power supply voltage frequency, $f$: 50 ÷ 1000 Hz;

– Luminance, $B$: 35 ÷ 50 cd/m$^2$ at $f$ = 50 Hz and $U$ = 220 V,

130 ÷ 230 cd/m$^2$ at $f$ = 1000 Hz and $U$ = 150 V (these values are typical for the panels manufactured by such well-known companies as: Ball Engineering and Lumenousfilm EL Products (USA), Sinel SPA (Italy), KEP-A1W and KEP-BW (China));

– Power consumption, $P$: ≤ 30 W/m$^2$ (KES-20W-200, KEP-D16W, KEP-A1W (China), Phosphor Products (UK));

– Input current, $I$: ≤ 0.2 mA/cm$^2$ (Lumenousfilm EL Products (USA), KEP-A1W, KEP-BW (China));

– Luminance non-uniformity, $K$: ≤ 5 % (Sumitomi Chem (Japan));

– Life time, $T$: ≥ 4500 h (Lumenousfilm EL Products (USA), Sinel SPA (Italy));

– Environmental conditions: – operating temperature range: + 10 ÷ + 50 °C, – ambient humidity: ≤ 95 %;

– Panel configuration is optional (by consumer request);

– Panel thickness is 0.4 ÷ 1 mm.

Among the listed ELP parameters, the most important for consumers are luminance $B$ and operation life time $T$, and this work is dedicated to their optimization.

## 2. DESCRIPTION OF THE EXPERIMENT TECHNIQUE.

ELP structure layout is given in Fig. 1.

It is determined that the luminance of this structure is influenced by following factors:

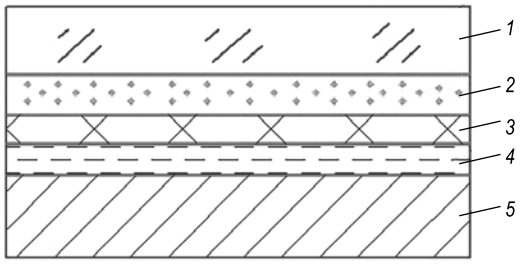


Fig.1. ELP structure: 1 – mylar film; 2 – indium-tin oxide transparent conducting layer *ITO* (10 % *SnO* + 90 % $In_2O_3$); 3 – fluorescent layer (phosphor suspension + dielectric binder in 2:1 weight proportion); 4 – dielectric layer (dielectric binder + $BaTiO_3$ in 2.5:1 weight proportion); 5 – opaque electrode (*Al, Ag*)

– Efficiency of the used phosphor, which is provided by the activating agent concentration and by the powder granulometric composition. In this work, a Chinese high-quality zinc sulphide electroluminescent turquoise phosphor D512C-GG is used.

– Quality of the liquid dielectric binder used for preparation of the phosphor suspension and the dielectric layer. Technological effectiveness of its application and relative dielectric permittivity value ε typical for it are important, because they directly influence the electric field action on phosphor grains and respectively on the luminance.

– Thickness of layers 3 and 4 (Fig. 1). It should be rather small to achieve the high field strength in the luminescent layer when voltage is applied to the ELP. At the same time there shouldn't be any glow irregularities because of an excessive depletion of the luminescent layer. Panels of our manufacture have phosphor grain diameter 25 μ, the thicknesses of the luminescent and dielectric layers deposited by silk-screen printing method are on average 60 and 40 μ respectively after curing.

– The high quality of the transparent electrode 2 deposited on the mylar film 1 (Fig. 1.) It should have surface resistance no more than 500 Ω·m.

– The optimum percentage ratio of the radiating and dielectric layers components. The components are as follows: dielectric binder on epoxy basis, electroluminescent phosphor, barium titanate being a ferroelectric material and oxyethylated phenol OP-10 being wetting agent.

– An optimum working mode of electric power supply. The excitation of electric fluorescent panels glow requires alternating voltage. In this case ELP phosphor radiates light quanta during both voltage half-cycles, and its instant luminance is a periodic function of time. One should provide a favourable combination of the supplying voltage amplitude and frequency, as well as pulse optimum configuration and duration [1, 2].

The studies have shown that a considerable potential for ELP luminance increase has the composition of the dielectric binder (DB), which together with the phosphor forms the fluorescent layer. DB is a polymeric dielectric, which in this case is prepared based on ЭД-22 resin. The binding dielectric should be transparent for visible light, have a good adhesion to adjoining layers, have a sufficient level of breakdown voltage, should be chemically insensitive relative to the filler and electrode materials. Optical and electro physical characteristics of the binding dielectric should be stable. This dielectric is not a binding material only but it also forms barrier areas and in doing so, it concentrates electric field directly on the phosphor grains. This field strength value can be computed using the expression:

$$E_{\text{in}} = E_{\text{av}} \frac{3\varepsilon_{\text{d}}}{\varepsilon_{\text{el}} + 2\varepsilon_{\text{d}} - \chi(\varepsilon_{\text{el}} - \varepsilon_{\text{d}})}, \qquad (1)$$

where $E_{\text{in}}$ is the field strength in the phosphor grains, V/m; $E_{\text{av}}$ is the average field strength in the layer as a whole, V/m; $\varepsilon_d$ is the relative dielectric permittivity of the dielectric binder; $\varepsilon_{el}$ is the relative dielectric permittivity of electroluminescent phosphor grains; $\chi$ is the phosphor volume ratio in the suspension.

It is apparent that the dielectric binder being a part of the phosphor suspension and of the dielectric layer should have a high dielectric permittivity $\varepsilon$ and small dielectric losses $t_{g\delta}$. This provides a maximum electric field concentration on the phosphor crystals distributed in the radiating layer and located separately from each other in the immediate vicinity of the binder. To increase $\varepsilon$, about 40 % of barium titanate being a ferroelectric material was added to the DB composition.

During the work, it was found out that polyvinyl alcohol cyan ether (PACE) is a very prospective material to be used as a part of films with high $\varepsilon$.

To obtain polyvinyl alcohol cyan ether, one should act according to the following formula:

$$\text{— } (CHOH - CH_2\text{—})_n + CH_2 = \\ = CH - CN = \text{— } (CHOCH_2\text{—}CH_2\text{—}CN)_n$$

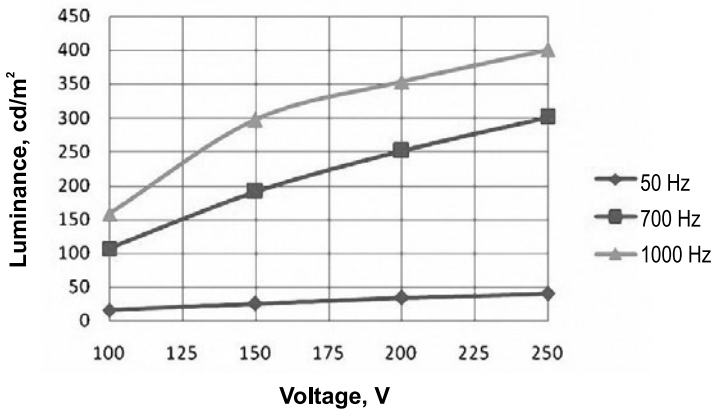


Fig. 2. ELP luminance dependences on power supply voltage for various frequencies

Polymerisation index $n$ can vary from 350 to 1200. A considerable concentration of high-polar mobile nitrile, carbonyl and hydroxyl groups in the PACE provides a high value of dielectric permittivity. At 1000 Hz frequency and the room temperature, it reaches 15 and more for $t_{g\delta} = 0.1 \div 0.15$.

PACE is a product of adding acrylonitrile to polyvinyl alcohol (PVA). Oxy groups are joined using activated double connection of acrylonitrile. It should be taken into consideration that the aceto group residue depends on the quality of the PVA manufactured at the supplier enterprise. More exactly it depends on the reached efficiency of acetate groups splitting out from polyvinyl acetate (saponification) instead of oxygroups until their residuum becomes equal to 1 %. And it is known that even insignificant presence of acetogroups as a part of the end product reduces its quality. And ideally, a superior quality saponified PVA should not contain oxygroups.

Using the synthesised PACE, we have manufactured ELP specimens. Luminance characteristics of such a specimen are given in Fig. 2.

PACE quantity added to the phosphor suspension is equal to 15 % of the phosphor powder mass. A significant luminance increase of the structures is reached in comparison with the specimens manufactured without PACE use, which at an average was about 25 ÷ 30 %.

However, $B$ can decrease drastically during continuous operation of the radiating films: it strongly decreases in the first 500 … 700 hours, and then the decrease slows down.

The studies have shown that the decrease of structure luminance was as a rule followed by a gradual change of its appearance. Fig. 3 shows a photo image of a film light source specimen manufactured by us after 600 h of its continuous work.


Fig.3. ELP specimen after operation

It is apparent that the luminescent layer darkened, and it is covered with little dark spots. Further operation of the structure aggravates the situation. Darkening of the luminescent layer can be indicative of its partial oxidation, which happens under the influence of the oxygen contained in the PACE.

Structural formula of polyvinyl alcohol can be presented as follows:

$$-(CH_2\text{-}CH)_n-$$
$$\quad\quad|$$
$$\quad OH$$

PACE obtained by synthesis of polyvinyl alcohol and acrylonitrile

CH2 = CH-CN has the following structural formula:

$$-(CH\text{-}CH)_n-$$
$$\quad\quad|$$
$$\quad\quad O$$
$$\quad\quad|$$
$$CH_2\text{-}CH_2\text{-}CN\ .$$

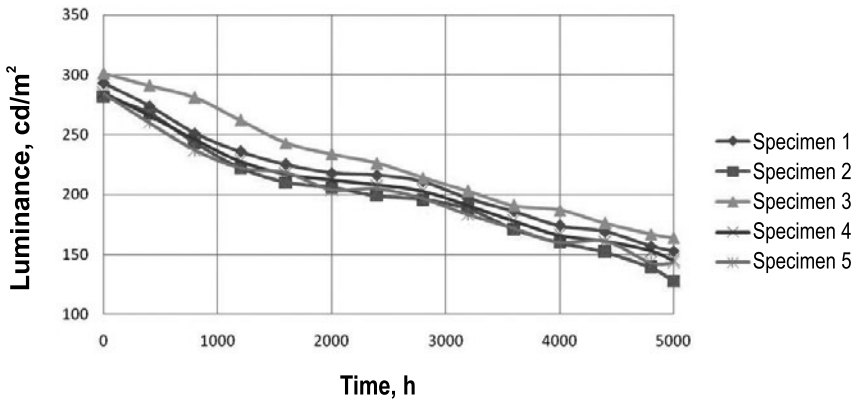


Fig. 4. ELP specimens life time test results (switch on mode: $U$ = 150 V, $f$ = 1000 Hz)

A new polar group CH2-CH-CN ramps up the growth of dielectric permittivity $\varepsilon$ of the polymer. And it is known that during the polyvinyl alcohol and acrylonitrile synthesis not all OH groups are closed. Oxygen, which remained untied in an OH group, can further facilitate oxidising processes in the luminescent layer and thereby decrease the ELP life time. In particular, the oxidation is sometimes manifested as the panel working surface darkening during its operation. And the panel degrades, changing its appearance (Fig. 3).

The performed studies have shown that a more perfect PACE analogue as a dielectric binder can be synthesised in the presence of *NaOH* catalyst paraformaldehyde, which initially has the following formula:

$$( - CH - CH - )_n$$
$$\quad | \quad\quad | \quad .$$
$$\quad OH \quad OH$$

The results of paraformaldehyde and acrylonitrile synthesis in the presence of NaOH catalyst are as follows:

$$(-CH - CH-)_n + H_2C{=}CH{-}CN \xrightarrow{NaOH} -(CH - CH)_n -$$
$$\quad | \quad\quad | \qquad\qquad\qquad\qquad\qquad\quad | \qquad\qquad\qquad\qquad\qquad\qquad\quad |$$
$$\quad OH \quad OH \qquad\qquad\qquad\qquad\qquad\quad O \qquad\qquad\qquad\qquad\qquad\qquad\quad O$$
$$\qquad\qquad\qquad\qquad\qquad\qquad\quad | \qquad\qquad\qquad\qquad\qquad\qquad\quad |$$
$$\qquad\qquad\qquad\qquad\qquad\qquad\quad CH_2\text{-}CH_2\text{-}CN \qquad\qquad\qquad\qquad\qquad\qquad\quad CH_2\text{-}CH_2\text{-}CN \; .$$

It is apparent that in the obtained polymer, on the one hand there are two polar groups, which increase the dielectric permittivity $\varepsilon$ of the compound. On the other hand, oxygen O is balanced (neutralised) by two links of polar groups. In this case one can expect a decrease of its oxidising properties in the whole polymer. A positive influence will be also exerted by absence of free OH group in the substance.

According to it, synthesis of PACE based on acrylonitrile and polyvinyl alcohol and intended to produce high-effective durable electrofluorescent panels, should be made so that the residues of oxygroups in it would be minimum. We have developed the correspondent synthesis technology. The product manufactured according to this technology has following useful properties:

– The high dielectric permittivity ($\varepsilon \geq 17$);

– The high transparency;

– A possibility to change viscosity, for example, by product dilution using dimetilformamide or acetone, which if necessary will change the ELP production process from periodic to semi-continuous (from silk-screen method to reel method of ELP production);

– The high thermal stability (up to 250 °C in the air);

– A possibility to harden films further both with ultra-violet radiation and temperature. In doing so, one should use correspondent radical polymerisation initiators.

The performed tests of the radiating structures that were manufactured using upgraded PACE, have shown that product life time increased to 5000 h. The test results of some specimens are given in Fig. 4.

Thus quite acceptable and competitive results are achieved for both ELP luminance and its life time.

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# FEATURES OF THE FORMATION RADIATION CHROMATICITY BY THE DISPERSION OF *CdSe/CdS/ZnS* QUANTUM DOTS IN MULTICOMPONENT SYSTEMS

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**ABSTRACT**

Quantum dots based on *CdSe/CdS/ZnS* have been broadly used lately in engineering and in some technologies, in particular connected with LED light sources, light-converting materials, fluorescent screens and video monitors. In some cases, there is a need for forming the chromaticity of the emitted light by mixing a dispersion of quantum dots with various optical properties. A broad and strong absorption spreading from the absorption peak of Bohr's exciton up to the UV spectrum region, leads to the additivity principle violation in the process of radiation chromaticity generation. It was established that the individual component maximum emission peak position depends on the concentration of quantum dots in the dispersion. It was also established that the dispersion chromaticity is influenced not only by the components ratio but also by the initial mixture dilution ratio.

**Keywords**: *CdSe/CdS/ZnS* quantum dots, emission peak, exciton absorption peak, fluorescence layers

At present, the practical use of new-generation phosphors based on colloidal materials with *CdSe/CdS/ZnS* quantum dots, are more and more expanded. In particular, the above mentioned quantum dots are used in LED light sources, light-converting materials for solar elements, cover materials for greenhouses, fluorescent screens for different purposes and in video monitors, as well as in some other technologies.

In most practical applications of the quantum dots, there is a need to create fluorescent radiation of a necessary colour by mixing quantum dots dispersions in certain proportions. It is found at present, that the colour of a self-luminous object without self-absorption and reabsorption effects can be determined by additive mixing of radiation intensities spectral distribution functions (for example, see [1–3]). Previously we have considered some aspects of the coloristics of fluorescence layers containing quantum dots in a situation, when the abovementioned processes can be neglected [4–6]. At the same time, these quantum dots have a wide absorption band spreading from the exciton absorption peak up to the near-ultraviolet region. Thus, when quantum dots with various fluorescence peaks maxima are introduced into dispersion, this inevitably leads to the fact that the component with a shorter emission wavelength falls within an absorption area of a component with a longer wavelength. In this case, in the process of the emitted light chromaticity formation the additivity principle is violated.

We suppose that a fluorescent specimen of the quantum dots dispersion has following properties. First, absorption in this media follows the Bouguer – Beer law and, due to the nanocrystal small size, the scattering in the dispersion is small. Secondly, the intensity of the radiation emitted by the speci-

men is proportional to intensity of the exciting radiation and to the fluorescence quantum efficiency. And finally, in the third place, optical density of a solution is small, and respectively, emission intensity appears to be proportional to concentration of separate components within the used concentration interval. In this situation, emission intensity depends only on the reabsorption. At a first approximation, the mathematical expression, which takes this effect into consideration, is as follows [7]:

$$E = E_0 \phi \left[1 - 10^{-(D_{\hat{a}} - D_L)}\right] \frac{D_{\hat{A}}}{D_{\hat{A}} + D_L}, \qquad (1)$$

where $D_B$ and $D_L$ are layer optical density at the wavelengths of excitation and emission correspondingly.

We used quantum dots with fluorescence in various regions of the visible range that were synthesized in authors' laboratory. The synthesized quantum dots consisted of a *CdSe* nucleus with an external shell based on *ZnS/CdS*. The synthesis was carried out [8] in argon atmosphere in a dispersion in a high-boiling organic solvent. To obtain the specified *CdSe* nucleuses, a mixture of *Cd* oleate (0.1 M) and octadecene (20 ml) was heated to a temperature of 270 °C. Then *Se* solution in octadecene (0.1 M) was added to the reaction mixture. Subsequently, the temperature was reduced to 230 °C, the mixture was allowed for several hours and washed free from unreacted precursors with the help of an ethanol-butanol mixture (of 3:2 composition) until precipitation. The obtained sediment was dispersed in toluene.

Then the build-up of a *CdS/ZnS* composition shell [9] was carried out layer-by-layer by mixing *Cd* oleate and octadecene at a temperature of 230 °C with addition of solutions of sulphur, *Cd* oleate and Zn oleate. Calculation of a necessary quantity of precursors was carried out taking into account *CdSe* nucleuses diameter and concentration [10]. Washing of the obtained quantum dots was performed by ethanol with a subsequent centrifugation.

Quantum dots with fluorescence maximum in the green spectrum region were synthesized on the base of *CdSe/ZnSe* nucleuses with *ZnS* shells. *ZnSe* nucleuses were previously obtained by injection of octadecene diethylzinc solution and trioctylphosphine *Se* solution into the reaction container with hexadecylamine at 310 °C. The nucleuses growth was performed at a temperature of 250 °C until the occurrence of emission with a maximum at 350 nm. After this, the solution temperature was decreased to 150 °C, and it was added to solution of trioctylphosphine oxide and hectilphosphon acid. Simultaneously dimethylcadmium and a trioctylphosphine *Se* solution were added to *ZnSe* solution. The resulting solution was kept at 150 °C until an emission peak at 540 nm appeared. The obtained nucleuses were reprecipitated according to the technique described above. Then the dispersion was added to trioctylphosphine oxide and hexaphosphon acid mixcture, striped of in vacuum, reprecipitated as above, and redispersed in chloroform.

Quantum dots with emission in the blue spectrum region [11] were obtained in inert atmosphere by introduction of oleylamin and molecular sulphur solution into a volume containing *CdO* and *ZnO* solution in oleic acid and octadecene at 300 °C. Then the solution was allowed at 270 °C for 45 min. After cooling, the nucleuses were reprecipitated in acetone and segregated by centrifugation with a subsequent redispersing in chloroform.

The build-up of the *ZnS* shell on the obtained nucleuses significantly raised fluorescence quantum efficiency. The build-up was made in oleilamin and octadecene mixture environment at a temperature of 200 °C by interaction with zinc diethylat and hexamethyldisiloxane in trioctylphosphine. The obtained quantum dots were reprecipitated using a standard technique.

The procedure of shell build-up significantly increases fluorescence intensity but the width of the nanocrystal radiation peak remains almost invariable [13] or even somewhat decreases.

Some properties of the synthesised quantum dots are given in the Table.

The characteristic size of a quantum dot nanocrystal *d*, which was reached during synthesis to obtain a present fluorescence peak wavelength, is connected with absorption wavelength in the exciton absorption interval $\lambda$ by the following empirical ratio [3, 12]:

$$d = 1.6122 \cdot 10^{-9} \lambda^4 - 2.6575 \cdot 10^{-6} \lambda^2 + \\ + 1.6242 \cdot 10^{-3} \lambda^2 - 0.4277 \cdot \lambda + 41.57, \text{ nm}, \qquad (2)$$

where $\lambda$ is expressed in nanometers, and in this case, molar extinction coefficient $\varepsilon$ at the exciton absorp-

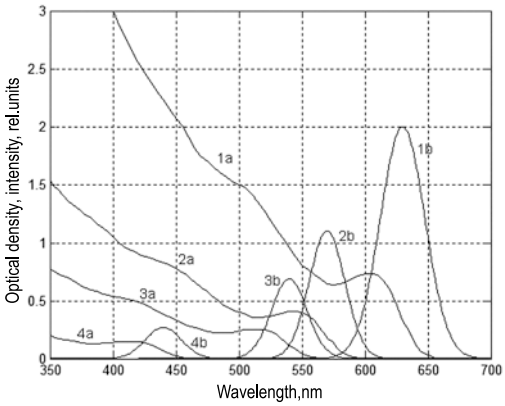


Fig. 1. Experimental spectra of absorption (a) and emission (b) of quantum dots with various optical properties. Fluorescence peak wavelengths: 1–630 nm; 2–570 nm; 3–540 nm; 4–440 nm

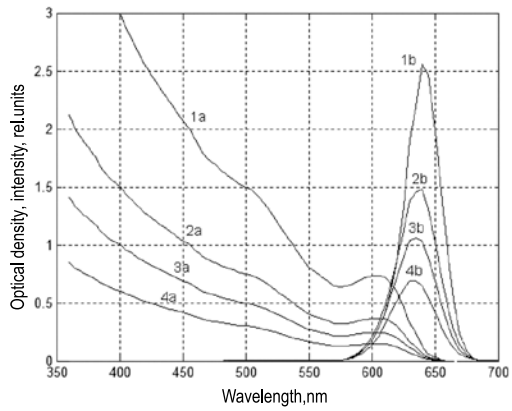


Fig. 2. Experimental spectra of absorption (a) and emission (b) of quantum dots with fluorescence peaks at about 630 nm for initial dispersion various dilution rates: 1 – undiluted (initial dispersion); 2 – twice; 3–3 times; 4–5 times

tion maximum can be determined according to the following expression:

$$\varepsilon = 5857 \cdot d^{2,65},\ \mathrm{M^{-1}cm^{-1}}. \quad (3)$$

And taking into account the assumptions listed above, the optical density $D$ of a layer is described by the formula:

$$D \approx \varepsilon CL, \quad (4)$$

where $C$ is the concentration of quantum dots dispersion (in a suitable solvent) and $L$ is the layer thickness.

The build-up of shells significantly increases the fluorescence intensity but the peak width and the absorbing ability of the nucleuses remain almost invariable [13].

For the measurements, dispersions in an unpolar solvent toluene were used. Measurements of the radiation intensity relative spectral density $E_{e\lambda}$ ($\lambda$) emitted by the quantum dots dispersion in the 350–700 nm interval were carried out by means of the *Cary Eclipse (Varian)* fluorimeter using a standard quartz cell of 10×10 mm size. The peak excitation wavelength was set within the interval of 350–400 nm. This allowed to obtain emission in the whole interval using only one exciting ray. The fluorescence intensity was recorded at an angle of $90^0$ to the exciting ray direction. Width of the slit of the exciting radiation source monochromator was set equal to 3 nm. Width of the receiver slit was set to be equal to 1 nm. Relative error of fluorescence peak contour measurement according to the fluorimeter passport was no more than 0.5 %. Absorption spectra were recorded by the *Specord 210* spectrophotometer in the same spectral region. Standard adjustment of the device is in detail described in the operation manual.

Experimental absorption and fluorescence spectra of quantum dots obtained by the method described above are given in Fig. 1. It is seen that emission peaks of the quantum dots with wavelengths less than 630 nm are within areas of intensive absorption of nanocrystals with greater wavelengths. The peaks are under influence of the self-absorption and reabsorption effects connected with the presence of nanocrystals of other sizes. Measured absorption and emission curves for dis-

**Table. Characteristics of the quantum dots used in this work**

| # | Peak wavelength of fluorescence, nm | Quantum efficiency,% | Composition |
|---|---|---|---|
| 1 | 630 | 85 | *CdSe/CdS/ZnS* |
| 2 | 570 | 75 | *CdSe/CdS/ZnS* |
| 3 | 540 | 60 | *CdZnSe/ZnS* |
| 4 | 440 | 55 | *ZnSe/CdS/ZnS* |

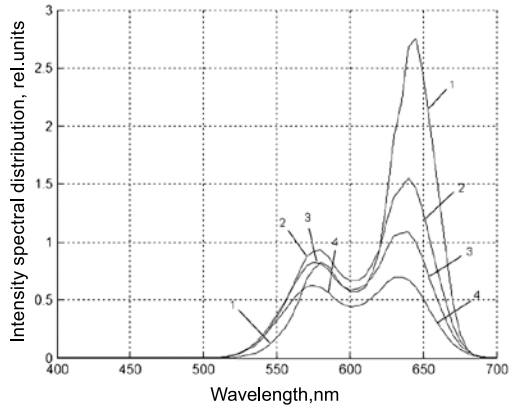


Fig. 3. Experimental emission spectra of a mixture of two types of quantum dots with fluorescence peaks at 630 and 570 nm for initial dispersion dilution (1): 2 times (2), 3 times (3), and 5 times (4)

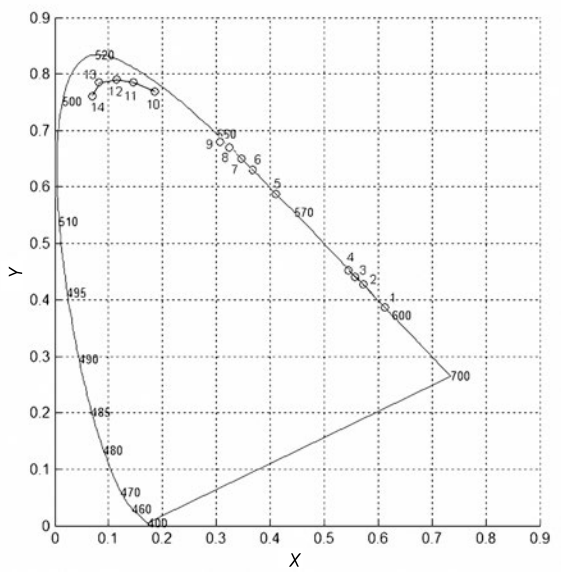


Fig. 4. Change of various composition quantum points dispersion radiation chromaticity during dilution of the initial mixture. The following mixtures of quantum dots are used: 1 – with fluorescence maxima at 630 and 570 nm, dilution extent is 1, 2, 3, 4, 5 times respectively; 5 – with fluorescence maxima at 570 and 470 nm, 5, 6, 7, 8, 9 – dilution extent is 2, 3, 4, 5 and 7 times; 10 – with fluorescence maxima at 470 and 440 nm, 11, 12, 13, 14 –dilution extent is 2, 3, 4, 5 times

persions with various extents of dilution of particles having one characteristic size are given in Fig. 2. It can be seen from Fig. 2 that emission peak configuration in a certain manner depends on self-absorption, because the peak falls both into the exciton absorption area, and partly into the anti-Stokes area. In this regard, when diluting a specimen, fluorescence maximum is shifted to the shortwave region by approximately10 nm. Fig. 3 shows emission spectra measured for a mixture of two type quantum dots with emission peak maxima at 630 and 570 nm.

Radiation colour (*X*, *Y*, *Z)* and of chromaticity (*x, y, z)* coordinates of the described above self-luminous objects were determined in a conventional way using the measured spectral functions $E_{e\lambda}$ *(λ)* [14–16]. Plotting of the chromaticity diagram (according to the CIE31 system) has showed that one of the most interesting colouristic effects in the system under consideration is the dependence of the chromaticity on the mixture dilution rate obtained for a given mixture (Fig. 4). Radiation chromaticity coordinates of quantum dots mixtures with fluorescence peaks at 630 and 570 nm, 570 and 470 nm and 470 and 440 nm are designated on the diagram by points. It is seen that due to rather narrow fluorescence peaks, chromaticity coordinate are located near the spectrum locus curve. In the process of the used mixtures dilution, chromaticity points are shifted along the spectrum locus curve to the blue region. It is connected with a reduction of the reabsorption effect contribution due to decrease of the photoactive components concentration in the dispersion. And at the same time measured colouristic effects are rather high for a normal observer.

Thus it is found that the colour combination additivity was not observed for the considered self-luminous object, and deviations from the additivity are the stronger the higher is the dispersion concentration. And to predict the chromaticity, one should take into consideration absorption spectra of all absorbing and fluorescent components. In this case, extinction coefficients can be on a first approximation assessed according to expressions (2) – (4), and distortion of the emission peak configuration can be approximately estimated using the already mentioned approximate expression, which takes into consideration the reabsorption effect. And the peak configuration also depends on the individual component concentration.

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# CONTENTS

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