ISCTE IUL
Instituto Universitário de Lisboa

HSE Management System and Efficiency Evaluation of Construction Projects

Zhang Honghu

Thesis submitted as partial requirement for the conferral of the degree of

Doctor of Management

Supervisor:

Prof. Leandro Pereira, Assistant Professor, ISCTE University Institute of Lisbon

Co-supervisor:

Prof. Chen Guangyu, Professor, University of Electronic Science and Technology of China

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Abstract

The strategy of “Belt and Road Initiative” actively advocates the establishment of economic partnerships with countries along the belt and road, and makes infrastructure construction a field for preferential development. It provides good development opportunities for domestic and foreign engineering contracting enterprises. The “Strategic Implementation Guidance Document” mentions that infrastructure construction and operation should be green and efficient. However, most state-owned engineering contracting enterprises do not attach importance to HSE management, which obviously affects the engineering efficiency and hinders the sustainable development of enterprises. However, China's engineering contracting enterprises pay less attention to HSE management, which obviously affects project efficiency and hinders the sustainable development of enterprises.

This study takes a typical large project contracting enterprise (Enterprise A) in China as the research object, adopts the SWOT analysis method, analyzes the weakness of project management at the organization level, and consummates the organization-level project HSE management system of the enterprise at the organization layer and the project layer. Through the enterprise interview, questionnaire design and investigation, this study puts forward the suitable indicators and methods of HSE management performance evaluation, and verifies the effectiveness of the methods through the empirical analysis of eight projects. Then, this study proposes incorporating the project HSE management performance into the comprehensive evaluation methods of project efficiency.

The empirical analysis shows that the HSE management system proposed in this study at the organization layer and at the project layer can improve the HSE management performance of the project. Project HSE management performance has a positive impact on project efficiency, that is, the more enterprises attach importance to project HSE management, the higher the degree of completion of project objectives. The above research results are helpful to improve project management system at the organizational level and enhance the competitiveness of project contracting enterprises.

Keywords: data envelopment analysis; construction project; HSE; comprehensive evaluation of project efficiency

JEL: D24; C67

Resumo

A estratégia da "Belt and Road Initiative" defende ativamente o estabelecimento de parcerias económicas com os países ao longo de uma determinada faixa e faz da construção de infraestruturas um campo preferencial para desenvolvimento. Este campo fornece boas oportunidades de desenvolvimento para as empresas de engenharia nacionais e estrangeiras. O "Documento de Orientação de Implementação Estratégica" menciona que a construção e operação de infraestruturas deve ser eficiente e sustentável. No entanto, a grande maioria das empresas públicas contratadas não atribuem a devida importância aos sistemas de gestão de saúde e segurança (HSE) o que, obviamente, afecta a eficiência da engenharia e dificulta o desenvolvimento sustentável das empresas.

As empresas privadas chinesas de engenharia ignoram a gestão HSE o que, obviamente, afecta, também, a eficiência dos projetos de sustentabilidade das empresas. Neste trabalho foi considerada uma grande empresa Chinesa de contratação (Empresa A) na China como referência de pesquisa, que adota a análise swot, analisa as fraquezas na gestão de projetos ao nível da organização e consuma a gestão de projetos em HSE ao nível da organização e do projeto em si. Através de entrevistas, questionários e investigação, este projeto apresenta os indicadores e métodos adequados de avaliação de desempenho e verifica a efetividade dos métodos através da análise empírica de oito projetos. Em suma, este projeto propõe incorporar métodos de avaliação da eficiência através dos indicadores de gestão do HSE.

A análise empírica demonstrou que o sistema proposto de gestão HSE, ao nível da organização e de projeto, pode aumentar efetivamente a gestão de performance do HSE em projeto. A gestão da performance do projeto HSE teve um impacto positivo na eficiência do projeto, ou seja, quanto mais as empresas atribuirem importância à gestão de projetos HSE maior será o nível de conclusão dos objetivos sustentáveis do projeto. Os resultados deste projeto são úteis para melhorar o sistema de gestão de projetos ao nível organizacional e aumentar a competitividade das empresas na contratação de projectos.

Palavras-chave: análise de dados; projectos de construção; HSE; avaliação da eficiência do projeto

JEL: D24; C67

摘要

“一带一路”战略积极倡导和沿线国家建立经济伙伴关系，同时把基础设施建设作为优先发展领域。其为国内外工程承包企业提供了良好的发展机遇。《战略实施指导文件》提到，基础设施建设和运营应当是绿色、高效的。然而，大多数国有工程承包企业并不重视 HSE 管理，这明显影响了工程效率，阻碍了企业的可持续发展。然而，我国工程承包企业对 HSE 管理重视不够，明显影响项目效率，阻碍企业的可持续发展。

本文以中国典型的大型工程承包企业 A 为研究对象，采用 SWOT 分析方法，分析组织级项目管理的薄弱环节，通过组织层面和项目层面完善企业的组织级项目 HSE 管理体系。通过企业访谈、问卷设计和调查，提出适合的项目 HSE 管理绩效评价指标及评价方法，通过八个项目的实证分析验证了方法的有效性。然后，提出将项目 HSE 管理绩效纳入项目效率的综合评价方法。

实证分析表明，本文提出的包含组织层和项目层的 HSE 管理体系能够提高项目的 HSE 管理绩效。项目 HSE 管理绩效对项目效率有正向影响，即企业越重视项目 HSE 管理，项目目标的完成度就越高。上述研究成果有助于工程承包企业完善组织级项目管理体系，提升企业竞争力。

关键词：数据包络分析；建设工程项；HSE；项目效率综合评价

JEL：D24; C67

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能够来到一座享誉世界的高等学府、成为一名成电学子，师从一位知识渊博的导师、结识一群才华横溢的师弟师妹，我想我是幸运儿。虽然此时此刻我们需要分别，但是我们的友谊天长地久。祝同学们前程似锦，祝母校蓬勃发展！

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Chapter 1：Introduction

1.1 Research background and significance

1.1.1 Research background

After visiting China's neighboring countries in 2013, President Xi Jinping proposed the joint construction of “the Silk Road Economic Belt” and “the 21st Century Maritime Silk Road”, later known as the Belt and Road Initiative. The Silk Road Economic Belt is a zone of economic cooperation between China and West Asian countries. The Maritime Silk Road was a sea passage for economic and cultural exchanges between China and other parts of the world 2,000 years ago. The construction of the “21st Century Maritime Silk Road” is a new trade channel for China to go to the outside world under the changing global political and trade pattern. Its core value is channel value and strategic security. This Initiative has aroused a warm response from the international community, and the strategic concept of the Belt and Road Initiative has gradually come into being.

In order to deepen and implement the important strategy of “Belt and Road Initiative”, Chinese government has promulgated a series of pertinent measures in succession. For example, in 2015, Chinese government promulgated the guideline for the implementation of the strategy of “Belt and Road Initiative” - Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road. Next, in order to meet the investment demands of the countries along “Belt and Road Initiative” for infrastructure construction, China took the lead in the establishment of Asian Infrastructure Investment Bank (“AIIB”). Therein, Vision and Actions proposes that infrastructure construction is an important part of construction. In addition, to respond to the environmental protection requirements of the international community, Vision and Actions points out that we should promote the construction and operation of infrastructures to develop in the direction of greening and low carbon. It is obvious that the greening management of the current construction projects is quite crucial (Zhang & Xie, 2017).

In the past 40 odd years of reform and opening-up, China has achieved continuous and rapid development in the process of urbanization, a lot of rural population has been gradually shifted to cities and towns, and the living standard and dwelling condition of people have been improved tremendously. As a core industry in the process of urbanization, the industry of engineering construction has been developing rapidly under the energetic boost of the process of urbanization. In particular, the achievement made by China in the infrastructure construction has attracted worldwide attention, so that the construction capacity of the enterprises in this industry has been improved obviously, having won the high recognition of the international community. According to statistics, the contractual amount of Chinese constructed engineering projects for other countries was USD 171.6 billion in 2013, and grew to USD 191.8 billion in 2014, and exceeded USD 210 billion in 2015. Notably, Chinese industry of engineering construction boasts a strong development momentum and development prospect both internally and externally, thus urging the project output and project quality of project contracting enterprises to develop in a higher and better direction.

In conclusion, considering the strong power of Chinese project contracting enterprises and the further boost of the strategy of “Belt and Road Initiative”, Chinese industry of engineering construction will still maintain a trend of continuous and rapid development in the forthcoming years, and the overseas construction projects undertaken by Chinese construction project contracting enterprises will also increase dramatically, especially the infrastructure construction projects of relevant countries of “Belt and Road Initiative”.

Along with the ever-increasing scale of present construction projects, the construction process and technology of projects become more and more complicated and the occupational health, safety and environmental management requirements in the process of project construction become higher and higher. However, a lot of large project contracting enterprises fail to pay enough attention to them, with serious liability-based accidents emerging endlessly.

In 1984, toxic gas leakage occurred to a pesticide factory in India, with more than 100 thousand direct victims, causing a major economic loss, and becoming the host horrible extra-serious accidents attributed to safety liability in the history. Today, the adverse effect of this accident on local residents still exists. In terms of process, the direct cause of this extra-serious accident attributed to safety liability is the explosion resulting from the chemical reaction between impurities and MIC. However, the fundamental cause of a lot of casualty is the backward safety management level of the factory. First, none of the alarming device, scrubbing tower, burning tower, water sprinkler system and other basic safety facilities of the chemical factory played their due protective role. Next, the control room of the factory paid little attention to the report made by a worker who discovered the irregularity, and factory failed to issue any warning to neighboring residents after the leakage of the toxic gas, so that a lot of unknowing residents were killed and wounded before taking any preventive measure. In addition, the problems posed by the Bhopal Incident not only include the design and construction of highly-risky chemical projects and the technological security in their operation, but also involve the lack of safety risk prevention awareness to highly-risky chemical products among the industrial regulatory bodies of India.

Engineering safety accidents have also emerging endlessly in China. For example, in 2016, an extra-serious safety accident occurred when Jiangxi Fengcheng Power Plant Project was put into operation in 2016, directly leading to 74 deaths and resulting in a serious casualty and property loss. The cause of this accident is that the construction unit failed to set up safety facilities and carry out all-round safety check according to the regulations of safety management in order to meet the deadline. This accident directly reflected the importance and urgency of a reasonable and effective mechanism of safety management.

In addition, the industry of engineering construction is a labor-intensive one, characterized by the labor subcontracting with a lot of rural migrant workers as major operation teams, a lot of outdoor operations, frequent high-altitude operations, mutual interruption of various jobs in the working face, and the high vulnerability of operation process and environment to the interruption of such factors as weather. These factors not only affect the working efficiency of workers, but also make site workers face serious health and safety threats. In addition, rural migrant workers tend to lack the knowledge of safety and environmental protection and have weak awareness of safety and environmental protection. In face of a complicated and changeable construction environment, how to ensure the safety of project construction, reduce or even avoid safety accidents, protect the practitioners' health, reduce environmental pollution and enhance project efficiency is a major problem that we need to solve immediately.

In terms of environment, according to statistics, the energy consumed worldwide in the construction and operation of construction projects of this type accounts for about 50%. As indicated by relevant Japanese researches, among all the sources of pollution of the global environment, those related to construction projects account for about 34%. Therefore, the greening management of construction projects is the most urgent and beneficial key measure at present. The Report of the Nineteenth People's Congress clearly puts forward the requirement of "building a beautiful new China". However, the overall construction industry of China lacks the awareness of environmental protection, pays little attention to ecological efficiency, and has a relatively backward management philosophy. Therefore, emphasizing environmental management is particularly important.

In conclusion, against the issues of occupational health, safety and environmental management in construction projects, it is very significant to set up a mature HSE management system in the building phase of construction projects and bring forward a mature comprehensive evaluation method of project efficiency.

1.1.2 Research significance

The study of this study has important theoretical value and practical significance, mainly reflected in the following two aspects:

1.1.2.1 Theoretic significance

In the past, in order to pursue short-term economic interest, Chinese project contracting enterprises overlooked occupational health, safety management and other issues in the management of construction projects, and failed to set up a mature HSE management system. In order to enhance the HSE management level of projects, we need to bring forward a suitable HSE management system of projects at the organization level, so as to set up a set of effective methods of occupational health, safety and environmental management for construction projects, thus providing effective methods for protecting the occupational health, safety and environment of project participants, promoting the competiveness of project contracting enterprises and meeting the sustainable development demands of enterprises and the society at large.

In order to enhance HSE management performance, we need to put forward a pertinent system of management performance evaluation on the basis of putting forward the system of HSE management of projects at the organization level , thus clarifying the level of HSE management, analyzing the shortcomings in HSE management, and bringing forward pertinent opinions on improving HSE management performance.

The present evaluation methods of project efficiency are chiefly built on the basis of the “three factors” of project management (quality, cost and progress), overlooking the key indicator that affects the sustainable development of enterprises and the society at large - HSE indicator, thus having difficulty in comprehensively reflecting the efficiency of construction projects. In addition, these evaluation methods also result that the managers of construction projects merely pay attention to quality, cost and progress management, and pay little attention HSE management, which cannot help to realize the sustainable development of enterprises and the society at large. Therefore, we need to bring forward more comprehensive evaluation methods of project efficiency. In order to solve the above-mentioned problem, this study not only considers the “three factors” of traditional project management, but also considers HSE management performance that affects the sustainable development of enterprises and the society at large, making the results of evaluation more comprehensive and objective, and drawing the attention of project managers to HSE management, so that they can try their best to enhance HSE management performance and attain the goal of sustainable development.

1.1.2.2 Practical significance

The system of occupational health, safety and environmental management (“HSE”) refers to a type of modernized management methods which aims at reducing enterprise risk by enhancing the level of enterprise health, safety and environmental management. HSE lays emphasis on risk prevention management, defining possible loss and hard before the event occurs, so HSE has a preventive nature. Therefore, putting forward the HSE management system of construction projects is realistically significant for smoothly implementing projects and enhancing project management efficiency, with the details as follows:

(1) The establishment and development of HSE management system can help enterprises to normalize their management system, and can help project contracting enterprises to enhance their project management level, so as to attain their goal of sustainable development. In addition, HSE management systems can improve the environment and behavior of enterprise construction through continuous institutionalized measures, which can help enterprises to meet relevant legal and statutory requirements. In addition, setting up an

HSE management system can help enterprises to meet international management requirements, undertake foreign projects and step onto the road of internationalized development.

(2) The establishment and implementation of HSE management system can reduce or avoid the loss of major construction accidents, and reduce operation risks. By carrying out the standards of the system of health, safety and environmental management, we can not only avoid risks to a certain extent before extra-serious accidents occur, but also try to effectively control staff and property loss during and after the extra-serious accidents and reduce the subsequent adverse effects brought by the accidents.

(3) The HSE management system can promote the effective connection of the economic and social benefit of project contracting enterprises. By improving the quality of HSE management, we can not only reduce and prevent extra-serious accidents, but also can improve enterprise image.

(4) Establishing the HSE management system can help project contracting enterprises to realize the green project management and shoulder social responsibility. On one hand, it can improve the relations between enterprises and local residents; On the other hand, enterprises can conduct reasonable arrangement and organization to staff, fund, materials, equipment and other resources, coordinate and unify various functional departments, and unify the economic, ecological and social benefit of engineering projects, so as to attain the goal of the sustainable development of enterprises, society, environment.

Therefore, by building the HSE management systems of construction projects and attaching importance to HSE management, large project contracting enterprises can comprehensively increase the benefit of engineering projects and attain the goal of sustainable development in the industry. The all-round study of the HSE management system and the objective evaluation of the management performance of construction projects can help to put forward the measures for ensuring the effective implementation of HSE management and enhancing management performance, promote the improvement of the evaluation standard system of the HSE management system of domestic construction projects, and also promote the all-round popularization of the HSE management of construction projects.

1.2 Research Framework and Main Research Content

1.2.1 Research Framework

The purpose of this study is to establish a suitable HSE management system for organization-level projects based on engineering contracting enterprises, and to propose a targeted system of management performance evaluation, so as to clarify the level of HSE management. In addition, this study considers incorporating the HSE management performance into the comprehensive evaluation indicator system of project efficiency, so as to make the evaluation results more comprehensive and objective. Furthermore, this study guides project managers to attach importance to the HSE management, improve the performance of HSE management, and attain the goal of sustainable development.

The research framework of this study is as follows: Chapter 1 describes the background of the development of Chinese engineering contracting enterprises and the requirements of the construction industry in the new era, puts forward the problem to be solved in this study--how to improve the HSE management of the project contracting enterprises, and points out the research value of the study. Chapter 2 summarizes and analyzes the existing research literature on HSE management, performance evaluation and so on. Chapter 3 analyzes the SWOT of Company A to find out the weak link of development. Chapter 4 constructs the HSE management system of Enterprise A at the two levels of organization and project. Chapter 5 constructs the indicator and method of HSE management performance evaluation by using AHP. Based on the indicator system of construction project efficiency evaluation including HSE management performance, Chapter 6 uses the DEA method to carry out the empirical analysis. Chapter 7 summarizes the entire study. The specific research framework is shown in Figure 1-1:

1.2.2 Main research content

This dissertation studies the evaluation methods of HSE management system and management performance of construction projects from the perspective of large project contracting enterprises, and builds the comprehensive evaluation method of project efficiency which includes HSE management performance. This dissertation contains the following parts:

Chapter 1: Introduction: expounding the future development trends of the engineering construction industry on the basis of “Belt and Road Initiative”, analyzing the problems with the present management of construction projects, putting forward the research purpose and significance of this study, sorting out domestic and overseas literatures in such three aspects as HSE, stakeholders and project efficiency, pointing out the shortcomings of existing research, bringing forward the research idea of this study, finally providing the research methods, research framework and innovative points of this study, and providing a guiding framework for next-step in-depth research.

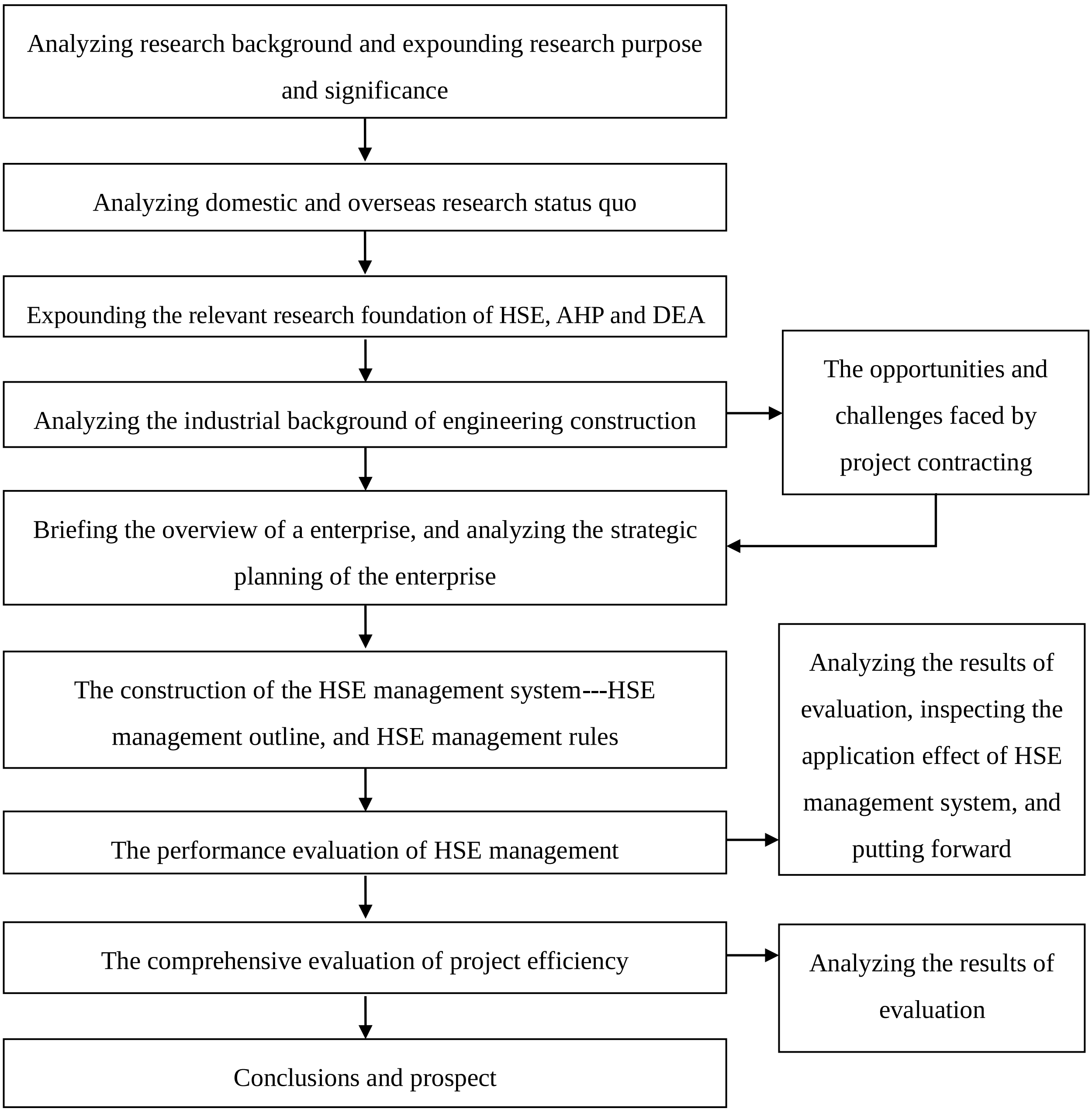

Figure 1-1 Research framework

Chapter 2: Relevant research foundation. First, expounding the relevant foundation of HSE in such two aspects as the development of HSE management and the core idea of HSE management; next, expounding the theoretical foundation of AHP method, including the construction of the judgment matrix, the acquisition of weights, the inspection of consistency and other major processes; finally, providing the relevant theoretical foundation of DEA, analyzing the construction idea and advantages and disadvantages of traditional CCR model, and the construction and idea of the super-efficiency DEA model and its advantages and disadvantages.

Chapter 3: The strategy and project analysis of enterprises. First, stating the source of data; briefing the overview and achievements of the Enterprise A; based on the above, analyzing the advantages and disadvantages of the Enterprise A by using SWOT and on the basis of international benchmark enterprises, and finding out its weakness.

Chapter 4: building the HSE management system of projects at the organization level: first, introducing the relevant content of enterprise interviews, including interviewees, and the problems with the HSE management of projects at the organization level; based on the above, proposing that we should establish a two-layer HSE management system - the implementation outline of HSE management at the organization level, and the implementation rules of HSE management at the project level.

Chapter 5: designing the performance evaluation methods and applications of HSE management of construction projects; with the eight projects contracted by the Enterprise A as the research object, setting up the evaluation indicators of HSE management performance, analyzing the performance of project HSE management by using AHP, analyzing the results, and putting forward the measures for enhancing HSE management performance.

Chapter 6: the comprehensive evaluation of the efficiency of construction projects: setting up an indicator system of efficiency evaluation of construction projects including HSE management performance; with the eight large projects contracted by the Enterprise A as the research object, analyzing project efficiency by using the DEA algorithm, conducting in-depth exploration to the results of evaluation, and bringing forward the suggestion for enhancing project efficiency on the basis of the results of evaluation.

Chapter 7: the summary and the prospect of the dissertation: reaching research conclusions by summarizing the whole dissertation, analyzing the defects of the dissertation, and providing an idea for future research direction.

1.3 Research methods and innovative points

1.3.1 Research methods

The research of this study comprehensively applies the questionnaire survey method, expert interview method, AHP and DEA. The details are as follows:

(1) Literature investigation. Consulting relevant literature to master the development and the existing research results of HSE management at the organization level, the evaluation of HSE management performance and the comprehensive evaluation of project efficiency, and to grasp the basic research methods and tools, thus laying the foundation for the research of this study.

(2) Expert interview. Through the method of expert interview, this study probes into the deficiency of HSE management in Enterprise A at the organizational level, and provides the basis for putting forward the feasible HSE management system, and quantitatively determines the weight of the management elements of HSE by the way of expert interview.

(3) Analytic hierarchy process (AHP). Aiming at the evaluation of HSE management level of construction project, the questionnaire is designed on the basis of the management elements of HSE. Through the expert interview, the HSE management level of the project is scored by the professional personnel of the construction unit, supervision unit and development unit of the project. Based on the score as the result of the questionnaire, the HSE management level of the project is measured by the AHP method.

(4) Data Envelopment Analysis (DEA). Because the evaluation of construction project efficiency should consider multi-input and multi-output indexes, and the dimensions of various indicators are often inconsistent, this study uses the method of data envelopment to analyze the project efficiency. In addition, through the projection analysis function of DEA algorithm, the resource input and benefit output of the project are deeply analyzed, and the allocation of input resources and benefit output are optimized.

1.3.2 Main innovative points

Against the HSE management of construction projects, this study builds an effective HSE management system at such two layers as enterprises and projects, and conducts comprehensive evaluation to HSE management performance and project efficiency. The innovative points of this study include:

(1) Supported by a large project contracting enterprise - the Enterprise A, this study comparatively analyzes a benchmark enterprise and finds out the advantages and disadvantages of the Enterprise A. By building a two-layer HSE management framework of project contracting enterprises, this study endeavors to promote the HSE management level of enterprises and projects and make up for the incompleteness of the management system of organization-level projects of enterprises, and then enhance the sustainable development capacity of enterprises and the society at large.

(2) Existing literatures have done little evaluation studies to the HSE management performance of projects. This dissertation builds the evaluation methods of HSE management performance with the AHP method, so as to conduct reasonable measurement to the HSE management level of projects, and then put forward pertinent improvement measures.

(3) Existing literatures chiefly evaluate the management level of projects through CPI, SPI, quality performance and other traditional indicators, and fail to comprehensive reflect the comprehensive management level of projects. This dissertation puts forward the comprehensive evaluation method which considers SPI, CPI, quality management performance, HSE management performance and other key indicators, comprehensively reflecting the attaining degree of resource input and project goals and the comprehensive management level of projects.

Chapter 2：Relevant Research Foundation

This chapter first introduces the relevant studies of “Belt and Road Initiative”, then introduces the relevant studies of construction projects; next, expounds the research foundation of HSE management from the perspective of the emergence and development process of HSE. Finally, expounds the relevant research foundation of AHP and DEA. The content of this chapter provides a theoretical basis for next-step in-depth studies.

2.1 Relevant studies of “Belt and Road Initiative”

Since Chinese government proposed the strategy of “Belt and Road Initiative”, numerous scholars have conducted in-depth studies to the relevant issues of “Belt and Road Initiative” chiefly in the following three aspects:

With regard to the interest of “Belt and Road Initiative”, Yu and Gu (2016) conducted in-depth research to the interest of the countries along the belt and road against the strategy of “Belt and Road Initiative”. The author held the opinion that, Chinese enterprises have mastered a lot of production science and technology and management experience in the past thirty odd years, which can be widely applied among countries along “Belt and Road Initiative”, meeting the demand of Chinese enterprises for overseas development. “Belt and Road Initiative” will enable Chinese industry of engineering construction to go abroad into countries along the belt and road, enable Chinese enterprises of engineering construction to expand their scope of operation, and enable export to alleviate the pressure of excess production capacity. In addition, because central and western China are regions most closely related to countries along “Belt and Road Initiative”, their infrastructure construction will be upgraded considerably, thus solving the problem of “the technological economy of western China lags behind that of central and eastern China” to a certain extent.

With regard to the risks of “Belt and Road Initiative”, Ling and Tao (2017) , Hua and Wang (2017) held the opinion that, as a major investment content of “Belt and Road Initiative”, infrastructure construction essentially involves the risks of large investment and long return period; next, Chinese infrastructure investment chiefly relies on fiscal expenditure, which can always ensure that enterprises earn a well-guaranteed income. In contrast, overseas infrastructure construction has a high degree of marketization, with a poorly-guaranteed income. Ling and Tao (2017) pointed out that the countries along “Belt and Road Initiative” indeed have huge demands for engineering construction, but most of their demands are “false demands” with construction expectations, without ability to pay for projects, and with a poorly-guaranteed enterprise return on investment. Wang and Lu (2017) analyzed the non-traditional safety risks of construction projects, with the results indicating that, the risks chiefly include political conflict, social security, natural environment, economic dispute and other types, and brought forward risk management suggestions in terms of such phases as project selection, tender offer, contract negotiation and contract execution respectively.

With regard to the boosting tactics of “Belt and Road Initiative”, Ling and Tao (2017) held the opinion that we should attach importance to whole-hearted cooperation with key countries, properly deal with the relations with countries along the belt and road, work out an overall plan and a reasonable layout and exert the unique advantages of overseas Chinese. Yu and Gu (2016) held the opinion that we should find the means matching the sustainable development of Chinese economy from an international point of view, should take steady and orderly steps and clarify key points, and should pay attention to the integration of domestic market, perfect the service system of the construction of “Belt and Road Initiative”, deepen reform, and eliminate the institutional barriers that restrict the international competitiveness of enterprises.

The above-mentioned studies were unfolded in such three aspects as the interest, risk and boosting tactics generated by “Belt and Road Initiative”, and the research achievements provided effective methods for guiding the implementation of the strategy, and pointed out a clear direction for Chinese project contracting enterprises to participate in overseas infrastructure construction.

2.2 The relevant studies of construction projects

Construction projects have been a hot issue of research for a long time. Because of their huge investment and high risk, scholars study them chiefly from such perspectives as risk management and safety management. In recent years, along with the gradual attention of the international community to environmental issues, the “greening” management requirement of construction projects has come into being at the right moment. Green construction projects have become a hot issue of research at present. The relevant studies of construction projects chiefly include:

With regard to the risk management of construction projects, Shao et al. (2011) held the opinion that the risks of international construction projects chiefly include economic, political, constructional and managerial risks. Li, Liu and Qi (2005) identified the risks of large construction projects and proposed five categories of major risks: social, natural, technological, economic and political risks, and further put forward the relevant countermeasures including the dispersion, retention, transfer and elimination of risks, providing an effective method for the risk management of projects. Xu, Wei, and Xu (2005) held the opinion that the whole-process risk management of projects can help enterprises to enhance their risk management level, avoid negative risks and successfully operate engineering projects. The author conducted detailed analysis to the whole-process risk management of projects in six aspects including the setup of risk management institutions and the formulation of plans.

With regard to safety management, Zhang, Huang and Fang (2006) conducted in-depth studies to the impacts of property owners on the performance of construction projects, and the results indicate that the following factors have a significant impact on the safety performance of projects, the setup of safety management institutions and the facilitation of a safety management meeting by the property owner on the construction site. Against the safety management problems of construction project groups, Yang (2010) built three project safety models by using the methods of single indicator and comprehensive modeling and dimension normalization, providing an approach for the safety management of project groups. Against international construction projects, Yang, Jia, and Lu (2013) proposed the SEM model of the impacts of the safety culture of international projects on safety performance, and the results indicate that the cultural concept of the management is the most important influencing factor of safety performance, and the cultural concept of the operation layer is where the difficulty of improving safety performance lies. Fang et al. (2012) built a matrix for evaluating the work safety responsibility of construction projects, providing an effective approach for fulfilling the work safety responsibility of various participants and enhancing the work safety performance of projects.

With regard to “greening” management, Wang and Yu (2006) explored the management of green construction projects. The author held the opinion that the management of green construction projects should include: the buildup of green project organization culture, popularization of green idea, formulation of greening standards of project management objects and active participation in international green certification. Based on studies of management models of green construction projects, Bo and Zhou (2010) held the opinion that design-building, construction management and project management contracting are the three major management models of green construction projects, and further analyzed the management characteristics and scopes of application of various models. Against the green evaluation issue of construction projects, Zhang (2016) built 19 important evaluation indicators at such four layers as qualification, management, technology and economy, and further built a decision-making method of bid evaluation based on multilayer grey correlation analysis, providing an effective method for selecting green construction contractors. Yang and Zhu (2017) explored the influencing factors of green construction project management in such three aspects as government, consumers and project organization, and conducted detailed discussion to the management of green construction projects by using AHP method. The research findings indicate that the external environment dominated by the government and market has a positive impact on the management of green construction projects as a whole, and the internal environment dominated by project organization has a negative impact. Wang and Wang (2014) analyzed the risks of green construction projects and extended out 22 green risks in such five aspects as environment, energy, resources, management and technology. Therein, environmental evaluation indicators include dust, exhaust gas, noise and vibration, light pollution, water pollution, solid waste disposal, surface environment destruction, underground facilities, cultural relics and resources destruction. Energy evaluation indicators include the application of high energy consumption equipment and machinery, the selection of high-energy-consuming construction technology, and the utilization of non-renewable energy. Resource evaluation indicators include the use of non-environmentally-friendly or non-green materials, the waste of construction materials, non-local materials, waste of water resources, and waste of temporary land. Management evaluation indicators include safety and health management, staff training management, planning and implementation of green risk management and information resource management. Technical evaluation indicators include the innovative research and development of green technology and the reliability of project implementation process, providing a basis for the green risk management of construction projects.

The above-mentioned literatures conducted in-depth researches to construction projects from such perspectives as risk management, safety management and “greening” management, providing an effective method for promoting the probability of project success. In addition, the concept of greening management provides scientific guidance for the future development trend of construction project management.

2.3 HSE related theoretical foundation

2.3.1 HSE development process

HSE management system is a comprehensive management system about occupational health (H), safety (S) and environment (E). This system originated from the petrochemical industry in the 1980s. In the 1980s, several extra-serious accidents in the petrochemical industry boosted the rapid popularization of the HSE management system. The theoretical development history of the HSE management system can be chiefly divided into the following phases:

Before the 1960s, most of the relevant studies focused on the management systems and principles with regard to safety. Enterprises continuously upgraded the safety and reliability of their equipment, facilities and production technology to upgrade the protection of their production workers.

In the 1970s, the researches in this phase focused on exploring the mutual relationship between production and environment, between workers and machines and equipment, and between worker health and enterprise interest. By exploring various determining factors of worker actions and formulating corresponding and effective management measures, behavioral science theory endeavored to attain management goals. An obvious feature in this phase was the gradual shift from management of “materials” to management of “people”; the management mode also gradually evolved into “participatory management”, beginning to attach importance to the mutual relationship between man and environment.

In the 1980s, the “people first” idea and environmental protection idea drew enterprises’ attention to the importance of employees’ physiological and psychological health, and a reliable and safe working environment to the perfection of enterprises’ technical process and the safety of enterprises' production process, and enterprises began to conduct in-depth development and comprehensive utilization to resources, reduce the emission of waste and protect the environment to achieve sustainable development. In this phase, the rudiment of HSE management system took its initial shape. Shell Oil Company played an important role in this phase. In 1985, when developing its oil mining projects, Shell Oil Company put forward a requirement of further reinforcing safety management. In 1986, the company compiled a corresponding Safety Management Manual. Shell Oil Company had world-class HSE management measures. It incorporated H, S and E into a complete management system, promulgated HSE Management Policy Guide and won unanimous recognition in the industry. From then on, HSE management system was gradually accepted by various large petrochemical enterprises worldwide, HSE management activities were spread rapidly worldwide, and international large petroleum companies began to imitate Shell Oil Company in succession, and adopted HSE management system as a new comprehensive management system. Moreover, in the 1980s, USA Dupont Company began to adopt HSE management system as an important measure for the enterprise to attain its business strategy goals, placed the safety goal at the layer of operation strategy, proposed that they would reduce the probability of all accidents by applying advanced management methods, particularly attached importance to the protection of the ecological environment, and set "zero injury, zero accident and zero pollution" as the HSE management goal of Dupont Company.

In 1990, the important concept of reinforcing risk evaluation and accident prevention was put forward at London International Cooperation Conference on Marine Oil Pollution. A lot of petrochemical projects reinforced their HSE management and regarded it as an important factor for judging whether a project was successfully implemented. By then, HSE management system had gradually become a key part of enterprise culture of large petroleum companies, with its status being even higher than that of the three goals of expense management, quality management and progress management.

At the end of the 1990s, HSE management system was further boosted, with its research content focused on the implementation and evaluation of HSE management system. The management concept of comprehensively applying the three at-the-same-times of "occupational health, safety and environment" was further put forward, with the focus being prevention management conducted before accidents occurred. The idea of prevention management was that HSE management system should bear "foreseeable, initiative, long-range and scientific" features. The direct or indirect economic loss caused by HSE accidents would be far higher than the cost for preventing accidents during HSE management (Nouri et al., 2007). The above-mentioned idea of prevention management boosted the further development of HSE management system, and laid a solid foundation for perfecting HSE management system.

2.3.2 The code idea of HSE management

The core idea of HSE management is building a "trinity" management system of H, S and E, laying emphasis on the comprehensive management of occupational health, safety and environment. Its management content chiefly includes the following three aspects:

(1) H (occupational health). H means people maintain a healthy state both physiologically and psychologically and avoid occupational diseases and other mental diseases. Each construction project involves a lot of participants, including managers, technicians, skilled workers and ordinary workers. Their physical and mental state would affect their working outcomes. For example, if workers are in a good mood and in a good physical condition, they would feel full of energy at work, would work much more efficiently, and would much less possibly commit errors at work which might lead to rework. On the contrary, they would work less efficiency and would be more liable to rework.

(2) S (safety). S means that enterprises are required to ensure the health of workers, avoid the loss of enterprise property and ensure people's life safety while engaging in production activities. Each construction project involves the risks of human dangerous acts and material dangerous states Therefore, during production activities, enterprises should require each worker or employee to have enough safety awareness, master work-related safety knowledge, and protect others and prevent themselves from injury at work.

(3) E (environment). E refers to various natural forces or resources related to human daily life and corporate production activities. Because H, S and E usually include and influence one another indivisibly in the process of daily management of construction projects, Health, Safety and Environment should constitute an integrated management system.

HSE management system is a reliable management method applied universally in the present international petrochemical industry against the H, S and E protection of workers. It has been widely applied in the global petrochemical industry, and has a mature effect of application, playing a crucial role in protecting occupational health, safety and environment. The building process of construction projects has many similarities with that of petrochemical projects, e.g. outdoor and high-altitude operation, air pollution, etc. By setting up an HSE management system in construction projects, we can upgrade the HSE management of projects and promote the coordinated development of project goals and the goals of sustainable development of enterprises and the society at large.

2.4 Domestic and overseas research status quo

In order to explore the construction of HSE management system and the evaluation methods of HSE management performance, and further conduct comprehensive evaluation to project efficiency, the thesis sorts out existing domestic and overseas researches in such three aspects as HSE related researches, stakeholders and HSE and project efficiency and performance.

2.4.1 HSE related researches

HSE management system was originated in the petrochemical industry, achieving a desirable effect. Domestic and overseas scholars have conducted in-depth theoretical study to HSE management system, enabling the theory of HSE management system to be rapidly popularized and practically applied. In China, China National Petroleum Corporation promulgated the System of Health, Safety and Environmental Management in the Petroleum and Natural Gas Industry in 1997, representing its official introduction and energetic implementation of HSE management system, and also representing the most advanced management level of Chinese HSE management system. Thereafter, the theoretical researches of HSE developed rapidly in China, and the application of HSE management system was gradually improved, namely a series of management methods established according to the model of planning, implementation, examination and improvement, attaining the HSE management goal of enterprises. Along with the intensification and development of Chinese HSE researches, the research scope of HSE management system in the academic circles began to develop from the petrochemical industry to the project construction industry.

In recent years, along with the vigorous development of Chinese project construction industry and the implementation of the policy of energy saving and emission reduction, the awareness of health, safety and environment of staff of project contracting enterprises has been rising continuously, and the HSE management system has been popularized extensively. With regard to the theoretical research of HSE management system in the project construction industry, Chinese scholars have conducted their implementation researches in design institutions, the HSE management researches of international general contracting companies and the HSE management researches in modern construction projects. As a result, the following urgent demand has taken its initial shape: project contracting enterprises should emphasize the need to conduct HSE management system construction for construction projects by applying the idea of HSE management system. Furthermore, Chinese scholars have brought forward corresponding implementation schemes and necessary problem-solving measures against this. Zhong and Han (2007) studied the necessity of setting up the HSE management body of construction projects. The author holds the opinion that the HSE management body is the manager of the occupational health, safety and environmental management system of projects, is the chief responsible department of HSE management, and is also a fundamental guarantee for attaining the HSE management goal. Since the HSE management idea was brought into China, numerous scholars have, from various perspectives, conducted in-depth exploration to the construction, improvement and evaluation of HSE management system. Domestic and overseas HSE theoretical researches are detailed as follows:

2.4.1.1 Research on HSE management performance evaluation

In the aspect of HSE management performance evaluation, based on the consideration of the impact of construction project risk on public safety, He and Chen (2005) proposed a reasonable governance approach-- the HSE management system of construction project, and analyzed the HSE management system of the construction project from the perspectives of management essence and core, theoretical basis and technical method, organization structure and performance evaluation. Li et al. (2015) constructed the HSE management performance evaluation system of petrochemical enterprises by expert weighting and fuzzy comprehensive evaluation method. Their research results provide an effective method for enterprises to evaluate the performance of HSE management, provide the basis for analyzing the weak links of HSE management, and provide the theoretical basis for improving the HSE management strategy.

By considering the possible characteristics of human error and data fuzziness in traditional power plant management, Azadeh, Farmand, and Sharahi (2012) proposed a model based on the management system of fuzzy data envelopment analysis (FDEA) to evaluate and optimize the performance of HSE management. In order to overcome the subjectivity and incompleteness of traditional risk analysis methods, Chen et al. (2013) constructed an evaluation model based on WBS- RBS and AHP. By considering the key factors of HSE management system and combining matter-element theory and quantification thought, Fang et al. (2013) established the evaluation principle of HSE, and provided a feasible theoretical method for optimizing the performance of HSE management. Wang et al. (2011) constructed the evaluation indicator system of SHE management performance based on the enterprise level by using AHP method. Lu (2012) evaluated the safety management performance of engineering contracting enterprises by using DEA method, and held the opinion that effective safety management was the key factor to improve the safety management level. Liu, Cao and Sui (2008) comprehensively evaluated the HSE management performance by using fuzzy mathematical model, and then determined the HSE management grade of enterprises. The evaluation system consists of five indicators and six dimensions, and the specific model is shown in Table 2-2.

Liu and Zhu (2009) designed the evaluation indicator system of the sustainability efficiency of construction enterprises at five levels, such as finance and engineering contracting, and set up the evaluation framework, and studied the calculation method of fuzzy identification and evaluation and enterprise performance level. With regard to safety factors, Xing, Tong and Zhang (2010) selected 7 primary indicators including human, equipment, environment, technical scheme, safety monitoring, construction procedure and purchase of safety materials and 24 secondary indicators including natural climate conditions. Among them, human factors include safety culture quality and execution ability at the layer of leadership, management and operation. Construction equipment factors include installation and control of equipment, reliability test of equipment and machinery and maintenance and upkeep of equipment. Environmental factors include natural climate conditions, construction site safety arrangements and construction site noise and light. Factors of safety monitoring activities include safety inspection, safety input level, safety education and training, safety protection, safety emergency handling and safety information transmission; Construction procedure factors include the construction task arrangement, the construction operation personnel arrangement, the execution of the construction-related plan, and the execution of the related building safety laws and occupational standards; The factors of safety material purchasing include time of material acquisition, quantity and quality of materials, and the implementation of purchasing guarantee system. At the same time, they used the methods of data mining, ANP and SD to establish the evaluation framework. Azadeh, Gaeini and Moradi (2014) used the DEA method to construct the evaluation method of HSE efficiency, which provides an effective way to optimize the management of HSE. Yan et al. (2014) put forward the performance evaluation method of HSE management system based on analytic hierarchy process (AHP). The author constructed the evaluation indicator system in six aspects: leadership commitment, policy, objective and contractor management.

2.4.1.2 Research on the influence of HSE management

In terms of the influence of HSE management on the success of the project, Miller and Lessard (2001) made a thorough analysis of the success or failure of 60 large construction projects. The results show that the main factor of project success is the management level of the risk and uncertainty factors. The uncertainty of the project is mainly affected by occupational health, safety and environment, that is, the level of HSE management has indirect influence on the success or failure of the project. By analyzing the key factors for the success of the construction project, Neringa (2013) held the opinion that factors affecting the success of the project included seven categories, including external, institutional, project-related, project-management-related, customer-related and contractor-related factors, and pointed out that the evaluation indicator of the project should be selected in these aspects.

Amiril et al. (2014) summarized 27 factors that affect the sustainable development of infrastructure projects in such five aspects as environment, economy, society, resource utilization and project management, and described the relationship between these factors and sustainability efficienc. Against the social environment faced by construction projects, Akanni, Oke, and Akpomiemie (2015) analyzed the impact of 29 social environmental indicators on the project efficiency by using the method of empirical research, from the perspective of the six kinds of social environmental factors, including politics, law, construction technology and resources, economy and finance, social culture and infrastructure. The research results show that the economic and the financial environment, and the political environment have the greatest impact on the progress of the project, while social culture has the greatest impact on the cost.

Zohreh and Napsiah (2014) studied the relationship between HSE management and sustainable development. The results show that working under the condition of physical and mental health and safety can improve the working efficiency and enthusiasm of the workers and then improve the production efficiency and quality. HSE management can not only improve the reputation of enterprises, but also reduce the production cost and increase the sales and income of products in the long run. The primary goal of sustainable development is to protect natural resources for future generations, taking into account the needs of modern people and society. In order to achieve the goal of sustainable development, work health and working environment safety play an important role in improving the enthusiasm of workers and productivity. HSE management and sustainable development have the same goal, which increases the probability of project success.

2.4.1.3 Research on HSE management system

In the aspect of HSE management system, Nouri et al. (2007) put forward the HSE integrated management system, that is, comprehensively using the traditional HSE management method and ergonomics. By means of electronic data exchange, team work and redesign of organization structure, the traditional HSE management system combined with ergonomics factors act on HSE management. The results show that HSE management system can improve the reliability, practicability, maintainability and safety of enterprises. The establishment of a sound HSE management system is of great significance to the production of enterprises. According to the characteristics of the ship management system for oceanographic research, Zhou et al. (2016) put forward the establishment of a HSE management system that conformed to the functions and management models of marine scientific research ships. The following points should be considered: (1) Managers should pay attention to the importance of resource investment, ensure its implementation, promote the concept of safety and environmental management, take the lead in creating a good HSE culture, and encourage crew members and research team members to erect the consciousness of self-protection; (2) Should lay emphasis on safety evaluation procedures, including risk identification, risk assessment and risk control; (3) Improve emergency management, prepare various emergency plans by experts in related fields, and formulate the plans as an important part of safety accounting and safety training after approval; establish and run the HSE management system on the principle of continuous improvement.

Edwards et al. (2013) held the opinion that HSE design should be carried out in the design stage of construction project, and pointed out that HSE design should run through the whole design stage. Introducing the HSE design in the design phase of the project can help to realize the close combination and seamless matching of the HSE management in the project design stage and in the subsequent stages, and provide the basis for the establishment of the HSE management method in the implementation stage. The key work of HSE in the design stage includes HSE analysis, the establishment of the project HSE management plan, the establishment of the project design foundation based on HSE element, the analysis of process hazards, the establishment of the fire prevention system and the conceptual design of equipment safety system, and the optimization design for the coordination between the equipment layout and HSE and so on.

Sun (1998) held the opinion that building HSE management system in line with international standards could improve the competitiveness of enterprises. For example, we should take an active part in the activities related to the international HSE management system, dispatch management personnel to go deep into the frontline construction site, make in-depth investigation to the construction work situation, invite international relevant experts to offer training and guidance in China, and so on. Gao (2011) analyzed the relevant overseas researches on the government regulation of occupational health and safety, and emphasized that the government's control power should be restricted and the mode of government regulation should be reasonable.

2.4.1.4 Research on key factors of HSE management

In the aspect of key elements of HSE management, Yang and Liu (2002) held the opinion that the safety management mode should be constructed to match the market economy, and summarized 7 primary indicators and 26 secondary indexes. Shen (2003) held the opinion that the operation of HSE management system included four stages of PDCA. Among them, the elements of the planning stage include: commitment of enterprise leaders, objectives of HSE management policy and responsibility of various management departments, elements of the implementation stage include: design and construction of equipment and facilities, etc.; elements of the inspection stage include: inspection, examination, supervision and accident handling and prevention; elements of the improvement stage include: audit, review and continuous improvement. By using the methods of PDCA and system analysis, Liu and Chen (2006, 2007) proposed that the improvement of HSE management system should go through four stages and eight steps.

Anne (2010) conducted a questionnaire survey of 9945 employees in 9 different industries, analyzed the relationship between health, safety and working environment by using the survey data, and further discussed the interaction between HSE management factors and occupational accidents. The results show that health, safety and the environment are closely related. The author held the opinion that the HSE management measures should help to establish the corresponding HSE management systems according to the characteristics of different projects. Qiang et al. (2004), Li et al. (2015) studied the relationship between safety investment and performance. The results show that safety performance assumes a natural exponential relationship with investment in labor protection and investment in safety per unit area, and safety performance is positively correlated with the investment in safety per unit area and negatively correlated with the per capita investment in labor protection.

China has done scanty research into the HSE management performance, which is one of the reasons for the difference between the HSE management level of our country and the HSE management level of the developed countries. China has not yet put forward a comprehensive and objective system to appraise project managmernt performance from a higher dimension. HSE management performance evaluation is an important part of current construction project management. In order to improve the performance of HSE management, enterprises must establish an HSE examination system and monitor the operation of the HSE management system to ensure its effectiveness. Therefore, the efficiency research should be based on the results of the implementation of evaluation management, and the description of the evaluation results should be used to determine the level of HSE management, and then a scientific and reasonable judgment should be made. In view of the fact that HSE management is a systematic job, performance should be evaluated objectively and impartially from a systematic point of view with.

2.4.2 Relevant studies of stakeholders

In recent years, although domestic studies of stakeholders are more and more intensive (Yang, 2003), the researches in this regard are still in their initial phase. Domestic studies focus on such issues as the definition of stakeholders, coordination degree and satisfaction evaluation. The details are as follows:

2.4.2.1 Research on satisfaction evaluation

With regard to satisfaction evaluation, Wu and Liu (2010) defined the comprehensive satisfaction of stakeholders of urban renewable resources with comprehensive evaluation methods of G1, entropy evaluation and fuzziness. Shang (2011) also did similar studies, and proposed that we should analyze the stakeholder satisfaction of Dalian DDZ by defining the weights with the G1 and entropy evaluation methods and establishing a model of fuzzy comprehensive evaluation.

2.4.2.2 Research on coordination

With regard to coordination degree, Chang, Zhang and Li (2014) set up a set of desirable tools of project stakeholder management from the institutional perspective on the basis of the synergetic theory, providing a quantitative method for measuring and improving the coordination degree of project stakeholders. Against the PPP project characteristics, He, Zhang, and Shi (2015) calculated the interest distribution coefficient by improving the traditional Shapely value method, which can not only promote the satisfaction of stakeholders, but also can adjust interest distribution against the actual project characteristics. From the perspectives of stakeholders, project value chain and game theory, Qi and Zheng (2015) built a value chain model of all stakeholders of construction projects. By bringing in the theory of stakeholders, Wang and Wang (2014) built a trust relationship network among construction projects and conducted quantitative studies to the trust relationship.

2.4.2.3 Research on the definition of stakeholders

With regard to the definition of stakeholders, Wu, Yao, and Liu (2011) defined the construction projects of the government deputy construction system, holding the opinion that stakeholders can consist of two categories (internal and external). The demand interface of internal stakeholders includes property owners and institutional users, and the supply interface includes deputy construction companies, project consultants and contractors. Among external stakeholders, the examining and approving departments include government reviewing institutions, etc.; supervisory departments include industrial institutions, etc., thus laying a foundation for working out more realistic and effective regulatory measures. Sheng, Qi, and Wang（2005）differentiated stakeholders of government investment projects, and classified them into primary and secondary stakeholders according to their correlation with projects.

Therein, primary stakeholders include relevant government departments, etc., and secondary stakeholders include social public, project communities, banks and government reviewing institutions, etc. Lv, Hu, and Guo (2013) classified stakeholders into three dimensions as shown in Table 2-1 from the perspective of such phases as project decision-making and planning and design respectively. Therein, the core stakeholders in the implementation phase are project deputy construction companies and construction enterprises. Ordinary stakeholders are social public, environmental protection organizations, governmental functionary departments, etc. Zhang (2015) studied the difference between engineering projects and company stakeholders, and the author held the opinion that the difference was mainly manifested as: different attitude toward projects or companies; different influencing modes and measures adopted when settling appeal; different timeliness of interest appeal, different complexities of stakeholder relationship; different information amounts, information sources and information flow-directions of operation or implementation; different degrees of mutual influencing among stakeholders and different relationships between goal attaining and stakeholders.

In addition, Zhang (2015) upgraded the management of stakeholders of single projects to that of project groups, and in connection with the complexity of their composition and the difference of the influencing scopes of various parts, proposed the idea of hierarchic management of stakeholders of project groups. The author classified the stakeholders of project groups into three levels according to their influencing scope: single projects, project groups and enterprises, and proposed the principle of “connecting multi-layer and cross-layer management. The research findings provide an effective approach for submitting the management efficiency of stakeholders of project groups.

Table 2-1 Stakeholders of governmental investment projects

Category	Decision-making	Planning and design	Implementation	Delivery
Core stakeholders	Investors; Relevant governmental management departments	Investors; Relevant governmental management departments; Survey and design institutions; Project deputy	Project deputy construction institutions; Construction institutions	Project deputy construction institutions; Construction institutions

		construction institutions; Project operation institutions		
Ordinary stakeholders	Project deputy construction institutions; Survey and design institutions; Project operation companies		Investors; Relevant governmental management departments; Survey and design institutions; Project operation institutions; Auditing and supervising institutions; Material and equipment suppliers; Environmental protection organizations; Neighboring masses	Investors; Auditing and supervising institutions; Project operation institutions
Marginal stakeholders	Auditing and supervising institutions; Construction	Auditing and supervising institutions; Construction		Relevant governmental management departments;

	institutions; Material and equipment suppliers; Environmental protection organizations; Neighboring masses	institutions; Material and equipment suppliers; Environmental protection organizations; Neighboring masses		Survey and design institutions; Material and equipment suppliers; Environmental protection organizations; Neighboring masses

Source: Lv（2013）

2.4.3 Stakeholders and HSE

Mao, Li, and Lu (2012) analyzed project stakeholders from the perspective of the sustainable construction of construction projects, and classified them into four categories: “core dominant type”, “core inducible type”, “supportive type” and “marginal latent type” , and pointed out that the stakeholders of construction projects bear the dynamic feature. The author further conducted in-depth analysis with the duties and appeal of stakeholders, and pointed out that governmental duties boost the maturity and perfection of green building market. The author held the opinion that the present project contracting enterprises had a low level of productive forces and technical progress rate, and the traditional construction models deprived construction enterprises of a lot of opportunities and impetuses to meet the requirements of sustainable construction. Therefore, project contracting enterprises fall into the category of “marginal latent type”. Zhang and Yin (2012) analyzed corporate social responsibility from the perspective of stakeholders, and explored such questions as WHAT, WHY and HOW. The author held the opinion that enterprises were very liable to overlook occupational diseases caused by environmental pollution and worsening employee working conditions and other issues of social responsibility, which not only has a severe impact on enterprises’ own sustainable development, but also will cause the waste of social resources and bring adverse effects on the harmonious development of the society. Against the issue of green building development, Wang (2016) proposed that we should formulate development strategies with the SWOT method and provide reference basis for decision-making.

From the perspective of project contracting enterprises, the institutional stakeholders of enterprises chiefly include property owners, design institutions, supervisory institutions, material and equipment suppliers, governmental regulatory institutions, internal employees of projects and neighboring masses (Chen & Zhou, 2011) with the details as follows:

(1) Property owners are the final owners of construction projects. The construction of projects is completed and the projects are finally put into operation exactly under the leadership of property owners. Therefore, property owners are the most important stakeholders of construction enterprises. The quality of projects concerns the usage function and repair and maintenance expenses of deliverables. These expenses are borne by property owners after projects are put into operation. Therefore, project quality is one of the most important appeals of property owners. Furthermore, the delivery time of projects has an impact on the fund recovery of property owners. The earlier a project is put into operation, the sooner the investment will be recovered. Therefore, project schedule is also one of the important appeals of property owners. Moreover, the safety management of projects is a major issue concerning national economy and the people’s livelihood. The safety control of projects is an important goal pursued by property owners (Takim & Adnan, 2008).

(2) With regard to construction projects, the duties of project contracting enterprises are developing activities according to construction drawings, and building them into physical objects. In the construction phase, the design of construction drawings has been basically completed. However, along with the continuous progress of construction, design change is inevitable. In order to conduct accurate design, the design institutions require construction institutions to provide accurate construction parameters. Therefore, the important appeal of design institutions is that the construction institutions should provide accurate construction parameters. Furthermore, if any quality problem occurs to a project, the most probable reason is no doubt that the design parameters are unreasonable or the construction institutions fail to exert strict control over quality. Therefore, quality is an important appeal of design institutions. Moreover, construction institutions complete the building process for construction projects, while the building process is the major phase when safety accidents occur. The safety management in this phase is particularly important. If any safety accident occurs, the economic loss and time loss for settling the accident is huge. Therefore, the safe implementation of projects is an important appeal of construction institutions.

(3) The major goals of supervisory institutions are quality, progress, safety and environment. Therefore, the major appeals of supervisory institutions are quality conformity, completion within the planned period, no safety accidents and reduction of environmental pollution.

(4) Governmental supervisory departments refer to those which supervise the construction process of construction projects, including quality supervision institution, safety supervision institution and environmental supervision institution. The appeals of governmental supervisory departments are no doubt quality conformity, no safety accidents and standardized emission of environmental pollutants.

(5) Enterprise employees are direct participants in the process of quality construction, with their interest appeals being work safety, no occupational diseases, and high personal income. The neighboring masses of projects are subject to the interruption of project implementation, with their important appeals being that their living environment cannot be destroyed due to project implementation.

The above-mentioned literatures explored the duties and appeals of stakeholders, and indicate that sustainable development is an important appeal of numerous stakeholders, namely, they have appeals for occupational health, safety and environment from different perspectives. Therefore, HSE management comprehensively reflects the appeals of stakeholders, is an important facilitating factor of sustainable development, and is also a new-type management requirement posed by stakeholders for construction projects.

2.4.4 Relevant studies of project efficiency and performance

2.4.4.1 Research on efficiency and performance

With regard to the connection and distinction between efficiency and performance, Takim and Adnan (2008) held the opinion that efficiency refers to the degree of realizing benefit output for a certain resource input, namely, the quantity of benefit output realized under a given condition of resource input. Xiao (2015) held the opinion that efficiency is an indicator for measuring the ratio of project input and output. This definition emphatically embodies the ratio between the resource input and benefit output of projects. Li, Wang, and Jin (2015) pointed out that performance is a measure of the attaining degree of planned goals, and this indicator embodies the attaining degree of intended goals, is the comparison between the actual benefit output and the targeted output, and emphatically reflects the attaining degree of planned goals.

With regard to the relationship between project efficiency and project success, project success consists of three parts - project management success, product success and project success. After project outcomes are delivered, the success of a project is evaluated with the degree of project completion under the constraint of cost and time and within the scope of implementation according to the degree of project output delivered according to specification. Short-term success can meet the demand and bring about profit, while long-term success means that the enterprise can attain a higher-level strategic goal and promote organizational performance. The project cost, time and quality are integrated as a quantity - the internal efficiency of project management with the help of fuzzy decision-making analysis, which is used to describe the management and execution level of the whole process of project.

In recent years, scholars held the opinion that traditional project efficiency should include such dimensions as time, budget and project scope. Efficiency is a comprehensive indicator for evaluating project resource input and benefit output (Li, Wang, & Jin, 2015). Adnan, Faisal, and Yasmine (2014) held the opinion that the evaluation of construction project efficiency is one of the major means of ensuring the rise of project management capacity, reduction of project delay, cost overrun and quality defect. Akanni, Oke, and Akpomiemie (2015) held the opinion that the success of construction projects relies on the success of project efficiency, and almost all unsuccessful projects are related to efficiency. Amiril et al. (2014) held the opinion that project efficiency and project success probability assume a significant positively-related relationship, and the author pointed out that building a reasonable model of project efficiency evaluation can have a positive impact on project team and promote the probability of project success. Meng and Gallagher (2012) studied the relationship between incentive mechanism and project efficiency, and the results indicate that the incentive mechanism can adjust the goals of project participants and promote project efficiency. Multi-layer incentive mechanism can enhance the overall efficiency of projects, while unitary incentive mechanism is more effective in boosting the project efficiency in a certain aspect.

Chen et al. (2015) built the prediction model of project success and failure by comprehensively applying the efficiency evaluation theory and hierarchic regression analysis, and studied the impact on project success and failure of the change trend of the efficiency of the communication, team, creativity, technology, risk, quality and resource management in the implementation phase of infrastructure construction projects, and then predicted the possibility of the eventual success and failure of projects. The research findings indicate that the performance of technical management has the largest impact on project success. Zhang and Zhou (2014) explored the intermediary role of the satisfaction of stakeholders between the "iron triangle" of project management and project performance, and the results indicate that it has an intermediary effect among quality, progress and project performance.

2.4.4.2 Research on efficiency evaluation

With regard to the evaluation of project efficiency, setting up a set of scientific and With regard to the evaluation of project efficiency, setting up a set of scientific and reasonable methods of project efficiency evaluation is always a hot issue of research in the field of project management. Overseas scholars have done in-depth researches in this regard. Based on the EFQM business excellence model established by European Foundation for Quality Management (EFQM), Bryde (2003) selected cooperative relationship and resources, the management process of project life cycle and other key performance indicators and built a model of project efficiency evaluation. He, Xiao, and Zhang (2017) held the opinion that the efficiency evaluation of construction projects should consider the sustainable development factor of enterprises and the society at large, while the three factors of traditional project management merely embody the degree of the efficient management of projects. Based on the above-mentioned ideas, the author proposed the evaluation method which comprehensively considers efficient management, satisfaction of stakeholders and market competitiveness indicators based on the DEA method, providing an effective approach for the all-round evaluation of the efficiency of construction projects. Against the large-scale, long-cycle, unique-task and other features of large scientific projects, Chen et al. (2015) built a dynamic evaluation method of project efficiency. During the construction of indicators, the factors of project layer and product layer were considered comprehensively, and a model of two-layer system dynamics simulation was built to evaluate its project efficiency. Lin, Lee, and Ho (2011) built the system of economic efficiency evaluation of Chinese local governments by using AHP and data envelopment DEA methods. Against the issue of efficiency evaluation of corporate technical innovation projects.

Chen, He, and Wang (2016) comprehensively considered the efficiency influencing factors at the project layer and the corporate organization layer, and put forward the evaluation method of project efficiency by using the system dynamics and DEA algorithm. Against the technical innovation features of construction projects, He, Xiao, and Zhang (2017) built indicators of efficiency evaluation and proposed that we should evaluate the efficiency of construction projects by comprehensively applying SD and DEA. According to the 2006 production data, Xi, Feng, and Jiang (2011) conducted relative effectiveness analysis to 4 enterprises and 6 water-saving projects in Tianjin, and the research findings indicate that industrial water-saving projects are more efficient than daily-life water-saving projects. Lu et al. (2009) proposed improved DEA methods to compare efficiency values of investment projects, thus providing basis for the decision-making analysis of project investment, Zhang, Liu, and Duan (2014) built an evaluation method of public transport project efficiency based on DEA. Against the issue of multi-project efficiency evaluation, Vitner, Rozenes, and Spraggett (2006) brought forward the evaluation method of multi-project environmental efficiency based on DEA, providing a scientific method for comprehensive multi-project efficiency.

2.4.4.3 Research on management performance evaluation

With regard to the evaluation of management performance, Tan and Xiong (2014) put forward a matrix for judging the importance degree of indicators in different phases, a matrix for judging the importance degree of indicators at different layers, etc., providing a method for the indicator construction and importance degree analysis of project performance evaluation. Cho et al. (2013) brought forward an evaluation model of management performance of R & D projects based on the AHP and Bayesian network method. This model calculated the weights of evaluation indicators with AHP, and rendered objective evaluation and rational analysis with the Bayesian network method. Jha and Chockalingam (2011) put forward the evaluation system of project progress management performance with the artificial neuron network method. Li, Liang, and Zhang (2015) designed an evaluation method of HSE management performance by comprehensively applying the expert weighting method and fuzzy comprehensive evaluation method. Horta and Camanho (2014) appraised the competitive position and management performance of Portuguese project contracting enterprises by combining DEA with decision-making tree induction method. Cetin and Filiz (2015) built a model of performance evaluation of software development project management with the neural network method.

With Three large project contracting enterprises in Vietnam as their research object, V. T., Luu, Kim, and Huynh (2008) evaluated the following Nine performance indicators of project contracting enterprises with the benchmark test method: cost, progress, satisfaction of stakeholders with service, satisfaction of property owners with products, quality management system, project team, project change management, project material management and worker safety management, further analyzed the project management methods of high-performance enterprises, and provided improvement strategy for low-performance enterprises. Based on the management performance of the project having been completed by the potential project manager of the new project, Hadad, Keren, and Laslo (2013) built a model of the decision-making support system of the selection of project manager of new projects, providing an effective method for decision-makers to select the most suitable project manager. The above literatures chiefly applied AHP, fuzzy comprehensive evaluation method, network AHP and artificial neural network method to analyze performance. The above methods put forward matching performance evaluation methods against specific research issues, and research findings have achieved a very good effect in practical application.

With regard to decision-making methods, Gad et al. evaluated the relative efficiency of several project proposals by applying the DEA method against project decision-making analysis, providing a methodological basis for project decision-making. Bouras (2013) provided a quantitative model for evaluating project efficiency, incorporating project cost and schedule quantification into the evaluation model, but held the opinion that it is very difficult to quantify such factors as maintainability and availability, so he failed to consider them in the evaluation system.

2.5 Analytic Hierarchy Process（AHP）

In 1973, an American famous operational scientist T.L. Satty put forward a method of scientific decision-making evaluation - Analytic Hierarchy Process (AHP). This method conducts multi-goal decision-making evaluation analysis in connection with qualitative and quantitative analysis. AHP applies the characteristics of behavioral science and quantifies the experience-based judgment of decision-makers. When the goal structure is complicated and necessary quantified data are absent, it is relatively practical to adopt AHP. AHP is an evaluation method of system analysis in the system science. The major types of solving problems include evaluation, decision-making, analysis, prediction, etc. The calculation process which applies AHP roughly includes the following steps:

2.5.1 Building a judgement matrix

Judgment matrix refers to the comparison of the degree of relative importance among the relevant elements at this layer against an element at the upper layer in a model of hierarchical structure. For example, if A_k in the factors of A layer and C_1, C_2, …, C_n in C at the lower layer are correlated, then the judgment matrix between A and C can be expressed as:

$$\mathbf{A} = (\boldsymbol{C}_{ij}) = \begin{bmatrix} \boldsymbol{C}_{11} & \boldsymbol{C}_{12} & \cdots & \boldsymbol{C}_{1n} \\ \boldsymbol{C}_{21} & \boldsymbol{C}_{22} & \cdots & \boldsymbol{C}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \boldsymbol{C}_{n1} & \boldsymbol{C}_{n2} & \cdots & \boldsymbol{C}_{nn} \end{bmatrix} \tag{2.1}$$

In the above equation, $C_{ij} > 0$, $C_{ij} = 1/C_{ji}$=1, $C_{ii} = 1(i,j = 1,2,\cdots,n)$; C_{ij} denotes the relative importance of C_i to C_j with regard to A_k. At this time, A is referred to as a positive reciprocal matrix. If various elements in a judgment matrix satisfy $C_{ij} = C_{ik} \times C_{kj}(i,j,k = 1,2,\cdots,n)$ among themselves, then this denotes that the judgment matrix conforms to consistency.

As the determination of indicator data and the assessment of values involve subjective judgment, in order to reduce the impact of subjective factors on the judgment result, we usually adopt the “1～9 ratio scaling method” proposed by T.L. Satty to conduct quantitative evaluation to the relative importance among evaluation indicators, just as shown in Table 2-2:

Table 2-2 The scale values of the judgment matrix and the definition of indicators

Scale value	Indicator definition
1	The two elements i, j are equally important
3	i is slightly important in comparison with j
5	i is obviously important in comparison with j
7	i is very important in comparison with j
9	i is extremely important in comparison with j
2，4，6，8	The ratio of the importance degree of i, j lies between the above two scale values
Reciprocal	If the ratio of the importance of i and j, then a_{ij}=$1/a_{ji}$.

2.5.2 Weight analysis

Single hierarchical arrangement refers to the relative importance between this layer and all elements related to an element at the upper layer, which can be obtained by calculating the eigenvector and eigenvalue of judgment matrix. If the maximum eigenvalue of a judgment matrix is denoted as λ_{max}, the eigenvector corresponding to λ_{max} is recorded as W (normalization processing), then the component W_i of the vector W is exactly the weight of the corresponding element. Under normal conditions, to apply AHP to calculate the maximum eigenvalue of judgment matrix according to a very high accuracy requirement, we can adopt the practical "root method" for approximate value calculation. The steps of an individual calculation are as follows: Step 1: calculate the product of each line of judgment matrix W_i:

$$\mathbf{W}_i = \prod_{j=1}^{m} z_{ij} \quad (i, j = 1, 2, 3, \cdots, m) \tag{2.2}$$

Step 2: work out the m root value of W_i, $\overline{W_1}$:

$$\overline{\mathbf{W}_1} = \sqrt[m]{\mathbf{W}_i} \tag{2.3}$$

Step 3: make normalization processing the vector $\overline{W} = (\overline{W_1}, \overline{W_2}, \overline{W_3}, \ldots, \overline{W_m})^T$:

$$\mathbf{w_i} = \frac{\overline{\mathbf{W_i}}}{\sum_{j=1}^{m} \overline{\mathbf{W_j}}} \quad (\mathbf{i}, \mathbf{j} = \mathbf{1}, \mathbf{2}, \mathbf{3}, \cdots, \mathbf{m}) \tag{2.4}$$

Then $W = (\overline{W_1}, \overline{W_2}, \overline{W_3}, \ldots, \overline{W_m})$ T is exactly the desired eigenvector.

Step 4: Calculate the maximum eigenroot of judgment matrix λ_{max}:

$$\lambda_{max} = \frac{1}{m} \sum_{i=1}^{m} \frac{\mathbf{ZW}_i}{\mathbf{w}_i} \tag{2.5}$$

In the above equation, ZWi denotes the ith element of ZW.

$$\mathbf{ZW} = \begin{bmatrix} \mathbf{ZW_i} \\ \mathbf{ZW_i} \\ \cdots \\ \mathbf{ZW_i} \end{bmatrix} = \begin{bmatrix} \mathbf{z_{11}} & \mathbf{z_{12}} & \cdots & \mathbf{z_{1m}} \\ \mathbf{z_{21}} & \mathbf{z_{22}} & \cdots & \mathbf{z_{2m}} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{z_{m1}} & \mathbf{z_{m2}} & \cdots & \mathbf{z_{mm}} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{W_1} \\ \mathbf{W_2} \\ \cdots \\ \mathbf{W_m} \end{bmatrix} \tag{2.6}$$

The purpose of carrying out consistency check is to test whether the relative weight evaluation of the respondent to various indicators is logical, so as to judge whether the weight obtained through the judgment matrix is reasonable, with its consistency indicator CI as shown in equation 2.7:

$$\mathbf{CI} = (\boldsymbol{\lambda}_{\mathbf{max}} - \mathbf{n})/(\mathbf{n} - \mathbf{1}) \tag{2.7}$$

In the above equation: λ_{max} - the maximum eigenvalue of the judgment matrix; n - the order of the judgment matrix.

If CI=0, then the judgment matrix is completely consistent. The smaller λmax-n is; then the smaller CI is, and the smaller the degree of its inconsistency is. In order to measure the size of CI, we can bring in the average random consistency indicator RI for measurement. If the random consistency ratio of the judgment matrix CR=CI/RI<0.1, the consistency of the judgment matrix can be regarded as satisfying the requirement. Otherwise, it is necessary to further analyze and adjust the relative value of the judgment matrix to make its consistency meet the requirements. In general, the final indicator of AHP analysis has multiple levels, so it is necessary to carry out the consistency test one by one to ensure the accuracy of the results.

2.6 Data envelopment analysis (DEA)

2.6.1 Traditional DEA model

American operational scientists Charnes, Cooper, and Rhodes (1978) proposed the method of data envelopment analysis (DEA) for efficiency evaluation. So far, the decision-making models of DEA method have achieved diversified development with their respective advantages and disadvantages. Therein, C2R model is a basic DEA model and is also a DEA model applied the most extensively, just as shown in Equation 2.8.

$$\begin{cases} \max \quad \dfrac{y_i^T u}{x_i^T v} = E_{ii} \\ s.t. \quad \dfrac{y_j^T u}{x_j^T v} \le 1 \\ u \ge 0, v \ge 0, j = 1, 2, \cdots, n \end{cases} \tag{2.8}$$

In Equation 2.8, E_{ii} denotes the self-evaluation value of DMU_i. By Charnes-Cooper, we can transform Equation 2.8 into an equivalent planning issue, just as shown in Equation 2.9.

$$\begin{cases} \max \quad y_i^T u = E_{ii} \\ s.t. \quad y_j^T u \le x_j^T v \\ x_i^T v = 1 \\ u \ge 0, v \ge 0, j = 1, 2, \cdots, n \end{cases} \tag{2.9}$$

In order to overcome the difficulty of Equation 2.9 in calculation and technology, Charnes and Cooper obtained the dual liner programming model of the above model with the help of Non-Archimedes infinitesimal, just as shown in 2.10:

$$\begin{cases} \min[\theta - \varepsilon(e_i^T s^- + e_i^t s^+) \\ s.t. \quad \sum_{j=1}^n x_j\lambda_j + s^- = \theta x_i \\ \sum_{j=1}^n y_j\lambda_j - s^+ = y_i \\ s^- \ge 0, s^+ \ge 0, \lambda_j \ge 0 \end{cases} \tag{2.10}$$

In Equation 2.10, θ denotes efficiency value, λj denotes the weight of evaluation indicator, xj denotes the input vector of the j th decision-making unit, and yj denotes the output vector of the j th decision-making unit. xi and yi are the input and output vector of the evaluated decision-making unit DMUi. ε is Non-Archimedes infinitesimal, n is the quantity of the to-be-evaluated decision-making unit, s- and s+ are slack variables. If θ=1，and s-≠0，s+≠0，then DMUi is weak DEA effectiveness；if θ=1，and s-=0，s+=0，then DMUi is DEA effectiveness；if θ<1，then DMUi is DEA ineffectiveness.

If the convex constraint condition $\sum \lambda_j = 1$ is added into the C2R model of DEA, then we can obtain the DEA-BC2 model, which can differentiate to-be-evaluated decision-making units into pure technological effectiveness and scale effectiveness. DEA-BC2 model is shown in Equation 2.11.

$$\begin{cases} \min \sigma \\ s.t. \sum_{j=1}^n \lambda_j x_j + s^- = \sigma x_0 \\ \sum_{j=1}^n \lambda_j y_j - s^+ = y_0 \\ \sum_{j=1}^n \lambda_j = 1 \\ \lambda_j \ge 0, s^- \ge 0, s^+ \ge 0, j = 1, 2, \cdots, n \end{cases} \tag{2.11}$$

In Equation 2.11, if the optimal value σ=1，then the decision-making unit belongs to technological effectiveness; otherwise the decision-making unit is non-technological effectiveness. If it is necessary to further judge the scale effectiveness of decision-making unit, we can order:

$$\mathbf{k} = \frac{\mathbf{1}}{\boldsymbol{\theta}^*} \sum_{j=1}^{n} \boldsymbol{\lambda}_j^* = \mathbf{1} \tag{2.12}$$

In Equation 2.12, k represents the returns-to-scale value of DMUi. When k=1, the returns to scale of DMUi remains unchanged; when k<1, the returns to scale of DMUi increases; when k>1, the returns to scale of DMUi decreases.

2.6.2 Super-efficiency DEA model

Since the DEA method has such advantages as objective evaluation results, this method has been widely applied since it was proposed (Wang, 2007; Huang, 2011; Tatari & Kucukvar, 2012). The traditional DEA models (C^2R, BC^2, etc.) can differentiate the decision-making units of evaluation into such two circumstances as DEA effectiveness or DEA ineffectiveness. However, with regard to decision-making units both of which are DEC effectiveness (namely the efficiency value is 1), traditional C^2R, BC^2 and other models cannot conduct further ranking to decision-making units effective for DEA. Therefore, traditional C^2R, BC^2 and other models cannot define the optimal decision-making units.

Against the above defects with C^2R, BC^2 and other models, Andersen and Petersen (1993) put forward the super efficiency- DEA (SE- DEA）model, which effectively solved this defect. SE-DEA model can differentiate DEA effectiveness decision-making units (namely the efficiency value is 1) and conduct accurate ranking.

Assuming that there are n independent decision-making units, the j-th decision-making unit has m resource inputs x-j and s benefit outputs y-j. The basic idea of the SE-DEA model is that, when the efficiency evaluation of the j-th decision-making unit is carried out, the inputs and outputs of the j-th decision-making unit are replaced by the linear combination of the inputs and outputs of the decision-making units other than j, thus excluding the j-th decision making unit, while the traditional C2R、BC2 model includes this decision-making unit. An effective decision-making unit can make its inputs increase proportionally, but its efficiency can remain unchanged. The ratio of increase in input is its super-efficiency evaluation value. The SE-DEA model is shown in Equation 2.13.

$$\begin{cases} \min \theta \\ s.t. \sum_{j=1, j \neq j_0}^{n} \lambda_j x_j + s^- = \sigma x_0 \\ \sum_{j=1, j \neq j_0}^{n} \lambda_j y_j - s^+ = y_0 \\ \lambda_j \geq 0, s^- \geq 0, s^+ \geq 0 \\ j = 1, 2, \cdots, n \end{cases} \tag{2.13}$$

2.7 Summary of this chapter

This chapter first expounds the relative foundation of HSE in such two aspects as the development process of HSE management and the core idea of HSE management system. Next, it specifically describes the theoretical foundation and calculation process of AHP method, including the building method of the judgment matrix, weight calculation and consistency test and other major steps. Finally, it provides the relevant theoretical foundation of DEA, analyzes the building idea and advantages and disadvantages of traditional DEA-C^2R and BC^2 models. Against the defects of traditional DEA models, this chapter expounds the buildup and idea and advantages of super-efficiency DEA model.

Chapter 3: Analysis of Enterprise Strategy and Project

With the Enterprise A as its research object, this chapter finds out its strengths and weaknesses under the strategy of “Belt and Road Initiative” by using SWOT, and finds out the current weaknesses of the enterprise.

3.1 Enterprise survey

3.1.1 Data source and processing

To analyze the strategic plan of the enterprise in the next phase, we need to gain a full understanding of the overview of the Enterprise A and its operation status in the previous phase, obtaining data chiefly in the following two aspects:

First, obtaining data through news, annual reports, etc. published via company website, with the major information content being enterprise profile, development overview, enterprise institutions and some achievements.

Second, conducting exchanges and interviews directly with internal staff and managers of the enterprise. The objects of exchange include the experts in Enterprise A and the key personnel participating in the construction projects, e.g. project manager, engineering designer. The main content of interviews is: investigating the development situation, staff, organization framework, business scope, enterprise (project) prize-awarding condition and other basic information of the enterprise from the economic management department of the enterprise; investigating the achievements of scientific and technological innovation from the department of scientific and technological innovation; collecting the key production and operation data of the enterprise in the previous phase from the compliance department, the department of operation and management, the department of finance and assets and other functionary departments; emphatically analyzing such key indicators as signed contract amount, operation revenue, profit amount, etc.; can obtain such indicators as operation revenue, signed contract amount and net profit amount through statistical analysis.

3.1.2 Enterprise overview and achievements

The Enterprise A is a large state-owned construction project contracting enterprise, with four Grade-A qualifications of general construction contracting, including municipal public utilities, mechanical and electrical installation, house building and petrochemicals. The main business of the Enterprise A is contracting the large construction projects of the above-mentioned specialties, with its business scope spread in 20 Chinese provinces, municipalities and regions including Beijing, Shanghai and Chongqing and such overseas countries and regions as Asia, Africa, South America and Australia. The Enterprise a now has about 2,460 employees, including more than 1,000 managerial and professional technical staff of various types, and about 146 senior technical talents. the Enterprise A has set up 9 branches including the No.1 Branch, the No.2 Branch, Project Management Branch and International Engineering Branch, and has set up functional departments in its group, including the Office of Legal Affairs, Department of Operation and Management, Department of Human Resources, Department of Finance and Assets, Department of Engineering Technology, Department of HSE Management and Department of Scientific and Technological Innovation. Its organization framework is shown in Figure 3-1.

As a large project contracting enterprise famous in the industry of engineering construction, the Enterprise A has a huge operation scale, and has been performing outstandingly in operation in recent years. The enterprise earned a business volume of up to X hundred million yuan and a net profit of X ten thousand yuan in 2013. The enterprise has been successively awarded more than 50 national, provincial and municipal collective honor prizes including “the May 1 labor certificate of merit of a city” and “national advanced enterprise in the building industry”. So far, the Enterprise A has completed the construction tasks of more than 100 large construction projects, 8 of which have been honorably awarded the highest honor prize in the Chinese building industry - Luban Prize, and more than 40 of which have been awarded provincial and municipal excellent project prizes.

Enterprise A maintained a continuous and steady development in the previous phase, and made remarkable achievements in development. Under the leadership of the management, the enterprise overcame the difficulties of sustained growth of investment, shortage of capital for construction units, sharp rise in production and financial financing costs, and market environment, gradually standardized the internal operation mechanism of the enterprise, actively opened up multi-operations, did a good job in internal management, and laid a good foundation for the long-term development of the enterprise.

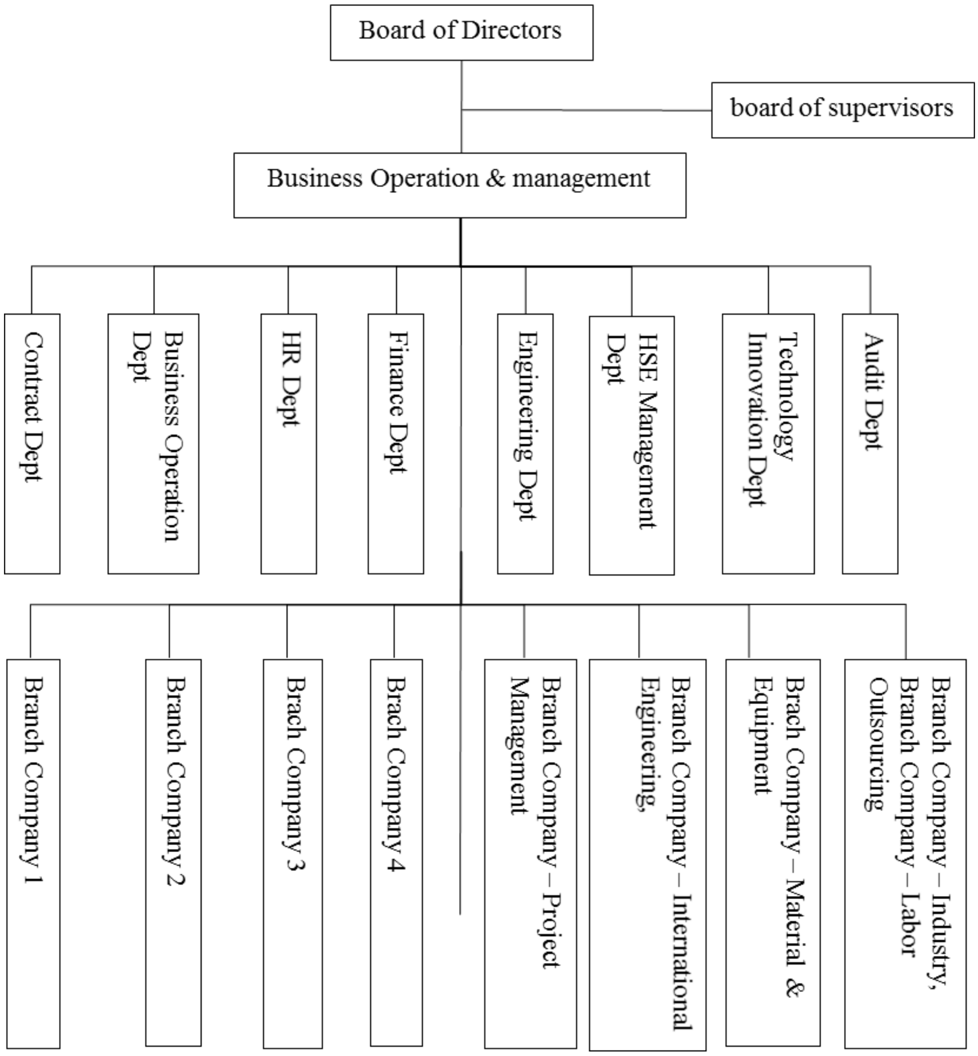

Figure 3-1 The organization framework of the Enterprise A

Source: Enterprise A database (2013-2017)

According to the statistical data, in the last period, the project undertaking contract amount of Enterprise A increased by 55.74%, the revenue of business increased by 21.60%, the total profits increased by 9.58% from the same period last year, and the per capita annual income of workers and staff increased by 23.32% from the same period last year. Major economic indicators and workers' income showed an overall steady growth trend. However there was a small decline in contract volume of project undertaking and the operating income in 2015. Evidently, Enterprise A has made rapid and steady development in the past five years, also laid a solid foundation for the next stage development.

In order to further expand its overseas market, Enterprise A has done a lot of basic and standardized work in mechanism innovation and system construction, and has gradually connected with foreign enterprises in internal management. At the beginning of 2010, the company started the system compiling work covering three levels: the company, branch company and project department. In July 2011, the company revised its system in an all-round way. In 2012, the company evaluated its organizational management system. In 2013, the company proposed to revise its system again. In 2015, the company completed the second revision of its management system and further improved its system.

The information management of foreign projects is particularly important. Therefore, in order to meet the management needs of foreign construction projects, Enterprise A has established and improved its information management system. The main contents are as follows: 1) The enterprise established the information control system of CAN quality management, carried out the whole process dynamic control of the material management, process management, electric equipment and electric instrument construction quality of the key and special major projects, and realized the dynamic management of engineering quality information; 2) The enterprise deepened its original NC system, developed the application system of "cost control", correlated the supervision, reward and punishment system of the enterprise with the "cost control" system, and carried out real time monitoring and information announcement to contract signing, payment for projects and other links, so that various jobs could be under supervision; 3) The enterprise upgraded the OA and NC system, upgrade and deployed the financial and human business system onto the same platform, and realized the uniqueness management and single-point log-in of users.

Construction project management and construction work are boosted steadily, and project cost, quality, safety and risk are basically under control. The management is mainly carried out in the following aspects: 1) all key projects of the enterprise require pre-planning. Project planning costs, safety factors and hazard source identification, quality and safety assurance measures, input resource allocation, project risks, etc. are evaluated comprehensively and specific implementation plans are put forwad to strengthen process control; 2) The enterprise carries out the centralized purchase of materials and the joint purchase of several projects to ensure the low price of the materials; 3) The safety and quality management work of Enterprise A runs in a systematic way. By establishing and perfecting the safety and quality management system, the enterprise strengthened the inspection of safety and quality and the special inspection in the construction process of projects. 4) The Audit and Supervision Department of the enterprise supervises the whole process of purchasing bulk materials, the tender opening of project subcontracts, the evaluation of bids, and so on, so as to prevent the occurrence of non-standard behaviors.

Improving the income level of workers and reinforcing the training of cadres and professional and technical personnel. The enterprise promoted the above mainly in the following aspects: 1) Gradually improving the welfare of employees, and steadily increasing the income of workers and staff; 2) Carrying out the training work in a down-to-earth manner, 14 Selecting and dispatching middle-level cadres to Tsinghua University to take part in short-term off-production training, starting the training in the design of construction drawings for the specialties of electricity, water supply and sewerage, HVAC and steel structure, training the design talents for the EPC mode project of the enterprise, organizing the excellent technical workers to carry out the special skill training, and organizing the in-depth training of the project standardization management.

Strengthening the enterprise culture construction, and enhancing the cohesive force among enterprise staff and workers. The enterprise has taken measures in the following aspects: combining the strategy of enterprise reform and development, actively planning the theme activities of enterprise culture, deeply excavating the essence of enterprise culture, shaping the brand image of a good enterprise, guiding the enterprise internally, cultivating the positive outlook on life, values and sense of responsibility among the enterprise staff and workers, advocating the spirit of honesty and trustworthiness, work loyalty and dedication, exploration, innovation and teamwork spirit, popularizing the core idea of the enterprise, forming a good situation of the unity of all for common development, raising employees' income, setting up the mechanism of talent identification and utilization, planned careers for employees. The investment and use of the new office building not only maintains and increases the value of enterprise assets, but also further improves the working environment of employees, and enhances their sense of identity and belonging to the enterprise. The enterprise launches the campaign of "delivering cool in summer and delivering warmth in winter", increasing the aid and support to straitened employees and their children.

3.2 SWOT analysis

The infrastructures of the countries along “Belt and Road Initiative” are relatively weak. One of the major strategic goals is to reinforce the infrastructure construction of these countries by using the rich experience of the project contracting enterprises of our country in infrastructure construction, so that the enterprises of our country can go toward the international market.

In addition, China has further intensified its overall layout in modernized construction, upgrading from “the four-sphere integrated plan” to “the five-sphere integrated plan”, beginning to attach importance to ecological civilization construction. The building process of construction projects tends to cause environmental pollution. Therefore, in the building phase, we must consider green, low-carbon and environmental protection. Attaining the goal of ecological civilization construction requires project contracting enterprises to make a greater progress and meet greater challenges. Excellent construction projects in the future are supposed to, based on environmental friendliness, provide people with a desirable living environment and promote the harmonious development between man and nature. Therefore, ecological civilization construction and engineering construction are closely related to each other, in which project contracting enterprises play a very important role. National strategy has brought a golden opportunity to project contracting enterprises, and has also posed a challenge to enterprise development, especially the challenge in the aspect of environmental protection.

Against the contracting and management problems with overseas construction projects, this study comparatively analyzes the strengths and weaknesses between the Enterprise A and a benchmark international project contracting enterprise (B enterprise) , and analyzes the opportunities and challenges faced by the engineering construction industry according to the external environment of the strategy of “Belt and Road Initiative”.

3.2.1 The advantages of the benchmark enterprise

B enterprise is a leading international project contracting enterprise in China, falling into the category of “an enterprise directly under central management”. The growth of the signed contract amounts of international engineering projects of this enterprise in recent five years has been higher than 10% every year, and its operation revenue of overseas projects accounts for

25% of its total revenue, but has an interest contribution of more than 60% (Sun, 2008). B enterprise is extremely famous in the field of engineering construction worldwide, and is a benchmark enterprise of overseas construction project contracting. Based on thorough investigation, we find out that B enterprise has the following strengths in undertaking overseas construction projects:

(1) Boasting a solid strength in the construction of industrial and civil buildings. B enterprise has special-grade qualifications of building project construction, and has a batch of project management contingents with a solid technical power and rich management experience. B enterprise has undertaken a large batch of large-scale industrial and civil buildings at home and abroad, and particularly has rich experience in the construction of large complicated projects.

(2) Having set up a perfect HSE management system. Since B enterprise has more than 20 years of experience in undertaking overseas engineering projects, and has rich experience in the management of overseas construction projects. In particular, the enterprise has set up a perfect system of HSE management in recent years. All its overseas projects are judged to be qualified during HSE management evaluation, and about 70% of them can reach the excellent or good level.

(3) Having core technology. B enterprise has multi-project core techniques in the aspect of project construction, which support its unique technical strength in undertaking overseas large industrial and civil buildings.

(4) A high degree of internationalization, and rich experience in the building of overseas construction projects. The overseas projects of B enterprise are spread all over the world, in which Asia, Africa and South America have the largest number, accounting for about 80% of the total of its overseas projects. Undertaking projects all over the world enables the enterprise to enjoy a unique advantage in meeting the requirement of globalization.

(5) A strong capacity of controlling the risks of overseas projects. With a high degree of internationalization, B enterprise tends to accurately identify potential risks with overseas construction projects and come up with feasible risk management schemes, thus having a strong capacity of risk response. In the past five years, all the overseas projects of this enterprise have attained major management goals including progress, quality, cost and HSE and won a favorable reception.

3.2.2 The Strengths of the Enterprise A

Both the Enterprise A and B enterprise are large state-owned project contracting enterprises. However, they have their respective features and strengths in project construction. In comparison with B enterprise, the strengths of the Enterprise A roughly include the following aspects:

(1) The Enterprise A has rich experience in the construction of municipal infrastructures and has a strong building capacity. The Enterprise A has been frequently awarded honor prizes in Chinese industry of engineering construction, and has a good reputation in the industry. In addition, the Enterprise A has set up a strategic partnership with numerous Chinese enterprises specializing in project contracting. Centering around the main business of the enterprise, based on strategic cooperation with the upstream and downstream enterprises of project construction, the enterprise has gradually developed a set of engineering project industry chain including project survey, design, construction, purchase and operation.

(2) The Enterprise A has a strong capacity of technical innovation, and now has 30 patent techniques and 41 construction methods. With a desirable capacity of technical innovation, the Enterprise A can establish innovative management modes, technical methods, etc. according to the unique construction requirements of overseas construction projects, thus ensuring the successful completion of projects.

(3) Before the implementation of the strategy of "Belt and Road Initiative", the Enterprise A had already participated in the construction of overseas infrastructures. In particular, the enterprise has contracted a lot of infrastructure construction projects in many countries in East Asia, with rich experience in building overseas construction projects. Furthermore, the enterprise has signed an agreement of long-term strategic cooperation with a large contracting enterprise of overseas construction projects, providing a strong guarantee for A company to explore the international market.

(4) Diversified operation models. Based on thorough cooperation with design institutes, banks, etc., the Enterprise A has preliminarily diversified its operation models. So far, several projects have shifted from the traditional model of general construction contracting to the EPC model of general project contracting. Several PPP projects are under negotiation. The implementation of EPC and PPP projects has expanded the operation models of the enterprise, helped the enterprise to further perfect its operation models and promoted the enterprise to

develop in the diversified direction.

(5) The perfect qualification system of the enterprise. The enterprise has four Class-1 qualifications of general construction contracting including electromechanics, building and municipal infrastructures and petrochemicals. Few institutions in China have these four Class-1 qualifications of general construction contracting, which not only meets the requirement of diversified development for enterprise qualification, but also reinforces the competitive strength of the enterprise in market expansion.

(6) Close cooperation with upstream and downstream enterprises of project construction. In order to further raise the added value of project construction, the Enterprise A has set up a strategic partnership with such professional institutions as survey and design, material and equipment suppliers and project operation to jointly participate in project implementation, upgrading the comprehensive and systematic management capacity of projects and raising the added value of project construction.

Compared with Enterprise A, the strengths of Enterprise B can be roughly divided into the following aspects:

(1) The enterprise has solid strength in industrial and civil construction; (2) The enterprise has set up a perfect HSE management system; (3) The enterprise has core technology; (4) The enterprise has a high degree of internationalization, and has rich construction experience of contracting foreign projects, (5) The enterprise has a strong ability of risk management for foreign projects.

3.2.3 The Weaknesses of the Enterprise A

Although the Enterprise A has undertaken the construction of several overseas engineering projects, it still has some weaknesses in undertaking the projects of infrastructure construction in countries along “Belt and Road Initiative”, roughly including the following aspects:

(1) The Enterprise A has insufficient experience in overseas project construction. On one hand, Chinese project contracting enterprises universally have the following weaknesses: insufficient experience in overseas development; lack of professional talents and knowledge reserve, consulting companies and professional institutions (Kan & Zhang, 2011), and the insufficient ability to respond to such risks as foreign laws, security, religion and environment. On the other hand, the overseas infrastructure industry does not have the support of national

finance, so overseas infrastructure investment cannot be guaranteed, and the income of project contracting enterprises cannot be ensured either. Moreover, for a long time, Chinese construction engineering projects have been conducted in the form of the separation and design and construction. Project contracting enterprises tend to only undertake the building tasks of construction projects. This model results that Chinese project contracting enterprises only have the capacity of project construction rather than the capacity of project design. However, overseas projects tend to adopt the EPC model of general project contracting, under which design, purchase, construction, etc. are all in the charge of the general project contractors (Zhang, 2015; Ang et al., 2017). This feature results that project contractors need to have the comprehensive capacity of design, purchase, construction, etc. at the same time. However, the Enterprise A has an obvious defect in design capacity, deterring it from undertaking overseas construction projects.

(2) Lack of core technology. Chinese project contracting enterprises lack the awareness of relying on proprietary technology and enterprise standards for leading in the market. A lot of general project contracting enterprises attach more importance to project scale and output value, and lack proprietary and patent technology based on independent intellectual property rights, resulting in such enterprise problems as weak advantage in technological competition. Nowadays, along with the increasing scale of construction projects and the increasing complexity of construction technology, higher requirements have been posed for the technical level and management ability of engineering contracting enterprises. The industry of engineering construction is gradually transitioning from a labor-intensive industry to a fund-intensive and technology-intensive industry. Large project contracting enterprises with a high degree of technical equipment, outstanding specialties, solid fund and advanced management are becoming the subjects of market competition, with their core technology being powerful capital of enterprise competition.

(3) The HSE management system of the Enterprise A is not sound enough. The Enterprise A did not begin to undertake overseas construction projects until a few years ago. Therefore, the construction of HSE management system of the Enterprise A is not as good as that of B enterprise. In face of HSE management problems, the Enterprise A tends to have insufficient pertinent management measures, and tends to be unable to meet HSE management requirements, which deters the Enterprise A from undertaking and administering overseas construction projects.

3.2.4 Opportunities of the Enterprise A

The strategy of “Belt and Road Initiative” further boosted the infrastructure construction of the countries along the belt and road, creating a golden development opportunity for Chinese project contracting enterprises. On the other hand, in terms of the current economic situation of China, the industry of engineering construction is still an important pull point of GDP. Nowadays, the opportunities of project contracting enterprises roughly include the following aspects:

(1) The background of the sustainable and rapid growth of national economy has provided a very good market environment for the development of the industry of engineering construction. According to “China will attain the development goal of doubling the GDP of 2010 by 2020”, the annual average growth of Chinese GDP in the forthcoming years will be not less than 6.5%. Therefore, benefiting from the sustainable growth of national economy and the boost of fixed asset investment, the Chinese industry of engineering construction will maintain a trend of steady advance for a very long time.

(2) The continuous boost of the strategy of “Belt and Road Initiative”. By September 2016, benefiting from strategic boost, the number of overseas contracting projects of Chinese project contracting enterprises had reached 3059, with a total contract amount of USD 59.11 billion, accounting for 54.3% of the total amount of Chinese overseas contracting contracts in the same period. Then, along with the continuous boost of the strategy of “Belt and Road Initiative”, this growth point will be expanded further, and the scope of project undertaking will no longer be limited to infrastructure construction, and will be extended to such sectors as service and energy.

(3) The great development of western China has entered a new development phase, and the construction of Chengdu-Chongqing Economic Zone and the high-speed development of Chongqing have brought a development opportunity to the industry of engineering construction. Not long ago, at the Planning Work Seminar of the Great Development of Western China, it was proposed that the overall layout of “five horizontal lines, two vertical lines and one ring” should be set up innovatively. At the same time, it was clearly proposed that the greater development of western China should be a prior development strategy in the overall strategy of Chinese regional coordinated development. In this period, Chinese government will offer vigorous support in such aspects as expanding the development of advantageous industries, boosting the

construction of livelihood projects and reinforcing infrastructure construction, so as to further accelerate infrastructure construction. (4) The huge space for the development of foreign contracted projects provides favorable conditions for the engineering construction industry to expand its overseas market. Between 2011 and 2015, the cumulative turnover of the contracted projects abroad was about 650 billion US dollars, and the new contracts were worth about 870 billion US. In general, the business growth rate remained within the range of medium and high speed, evolving from the explosive growth in the last stage to the new normal of healthy and stable growth. In 2015, the turnover of China's foreign contracting project business was about 150 billion US dollars, and the new contracts were worth about 210 billion US dollars, exceeding $200 billion for the first time. At present, the strategy of "go-global" is in the special period of the “confluence” of the stage of primary development, the stage of rapid growth and the stage of transformation and upgrading, which is also the key period for China to realize new leapfrogging in the development of foreign contracting engineering and labor cooperation. Judging from the long-term development trend, the space for the development of foreign contracting projects is still huge and the prospects for development are good.

3.2.5 Threats of the Enterprise A

Along with the proposition of the strategy of “Belt and Road Initiative”, there are some threats at the same time for the contracting projects of construction engineering of China in countries along the belt and road, including:

(1) The demand for “people first” and environmental protection is higher and higher and worker employment and profit management are more and more difficult in the international community. The building workers of the current construction projects not only pursue high income, but also pursue a safe and comfortable working environment. Because of the building feature of construction projects, workers need to engage in outdoor operation, high-altitude operation, etc., so that workers are often located in an adverse and dangerous working environment. The original workers no longer engage in the industry of engineering construction, and new employees are prudent to engage in this industry. This makes it more and more difficult to employ the workers in the industry of engineering construction. This requires projects of construction engineering to improve workers’ occupational health and safety management and create a comfortable and suitable workplace for workers. On the other hand, the environmental problem has been more and more prominent in recent years. In particular, the

serious haze weather of several Chinese cities enables environmental protection to be reinforced, and the model of economic development at the price of environmental pollution has already been abandoned. The building process of construction projects will inevitably cause environmental pollution. The rise of the awareness of environmental protection of all people forces managers of construction projects to exert stricter management over the problem of environmental pollution. Therefore, there are more and more management factors of construction projects; the requirements are stricter and stricter; the difficulty is greater and greater.

(2) In terms of political crisis threats, West Asia and North Africa have an unstable political situation and undesirable regional situations. Therefore, once such problems as wrong publicity and wrong interpretation occur to the strategy of "Belt and Road Initiative", neighboring countries will probably repel this strategy, unnecessary political imagination and misunderstanding may occur (Ling & Tao, 2017), the doubt of neighboring countries may arise and Chinese project contracting enterprises will face a huge political risk overseas.

(3) In terms of economic threats, infrastructure construction is concentrated in developing countries, with many development opportunities and a big potential. However, the present trend of economic growth is unclear, without manifesting any forceful development form. The project contracting enterprises of developing countries universally have such problems as weak foundation, weak anti-risk capacity and unreasonable structure in economic development.

(4) In terms of legal threats, Continental, British and American and Islamic and other legal systems are involved in the legal policies of the countries along "Belt and Road Initiative". In the engineering construction of "Belt and Road Initiative", the contracting subjects are Chinese state-owned enterprises, which can be very easily judged to constitute an act of invasion by other legal systems. Therefore, the normal business acts of state-owned enterprises would be rejected on such pretexts as security, monopoly and dumping, and it would be very difficult to guarantee the interest of these enterprises.

(5) In terms of threats of capital recovery, infrastructure construction chiefly covers transportation, water conservancy, municipal projects and involves a lot of investment and the coordination of local governments of countries along the belt and road. Therefore, infrastructure construction has some risks in this regard. On the other hand, projects of infrastructure construction have a long period of construction and a long time of capital

recovery. Therefore, the normal flow of capital chain of project contracting enterprises is a big problem.

(6) Along with the advent of the break point of population, the industry of engineering construction faces the plight of employment. As known to all, labor intensiveness is an obvious feature of the industry of construction engineering. However, along with the drastic change of global industrial structure, the market of human and labor resources has been shifting from “the tide of migrant workers” to “labor shortage”. This trend results in the dramatic rise of the human cost of construction engineering projects. Although artificial intelligence is very popular at present, it would be very difficult to use robots for labor for a very long period in the future, especially excellent project managers and professionals in such aspects as costing, materials, quality inspection and safety.

(7) The fierce competition among general construction contractors. Chinese industry of construction engineering assumes an obvious inverted triangle. There are numerous enterprises with the qualification of general construction contracting of construction projects, but there are few contracting enterprises engaging in specialized engineering projects, let alone enterprises engaging in specialized labor contracting. As a result of this feature, numerous projects contracting enterprises have the qualification and capacity of contracting domestic large construction projects, and the competition of general construction contracting enterprises in China is particularly intense. Promoting enterprise reputation, establishing unique competitive edges and going toward overseas markets is an effective approach for the development of large project contracting enterprises.

3.3 The analysis of the strategic plan and goals of the Enterprise A

3.3.1 SWOT-based strategic planning analysis

Based on the external opportunities and threats faced by the enterprise and the internal strengths and weaknesses of the enterprise as analyzed above, this study analyzes the strategic planning of the Enterprise A with the SWOT method, with the details shown in Table 3-1.

Table 3-1 The SWOT analysis of the strategic development of the Enterprise A

	Strengths	Weaknesses
	1. Rich experience in infrastructure construction; 2. A strong capacity of technical innovation; 3. Diversified operation modes; 4. A perfect system of company qualification; 5. Close cooperation with upstream and downstream enterprises of project construction.	1. Insufficient construction experience of overseas projects; 2. An insufficient system of HSE management; 3. Absence of core technology;
Opportunity 1. A huge development space of overseas contracting projects; 2. The greater development of western China and the construction of Chengdu-Chongqing Economic Zone has brought a development opportunity for the industry of construction engineering; 3. “Internet +” has stretched out a lot of new development directions for the development of the industry of project contracting.	SO growth-oriented strategy 1. The main business is the municipal infrastructure projects in countries along “Belt and Road Initiative”; 2. Promoting the construction management capacity of infrastructure projects; 3. Formulating corresponding project contracting schemes according to the features of the countries along “Belt and Road Initiative” by applying the advantage of technical innovation.	WO torsional strategy 2. Continious improvement on HSE Management system. 3. Use “Internet +”to introduce and apply core technology for further innovation.
Threats	ST multi-operation strategy	WT defensive strategy

1. The awareness of "people first" and environmental protection is reinforced in the international community, the requirements of HSE management are strict; the difficulty of project management is great; 2. West Asia and North Africa have uncertain political situations; 3. Some countries have weak national economy and insufficient anti-risk capacity and have difficulty in recovering capital; 4. The legal systems of countries along "Belt and Road Initiative" are diversified; there is a risk of unfamiliarity with the laws of corresponding countries; 5. Along with the advent of the break point of population, the industry of engineering construction faces the plight of labor.	1. Pay attention to HSE management and ebuild up awareness of HSE management 2. Cooperating with banks and other financial institutions, jointly investing in projects, promoting the capacity of resisting funding risks. 3. Develop diverse project contracting Models such as EPC, PPP, etc.	1. Abandoning overseas markets, focusing on domestic markets; 2. Focusing on the current main business, and waiving the exploration of a new management model.

As inferred from Table 3-1, the Enterprise A can select an appropriate development strategy according to the next-step development goal of the enterprise from among such strategies as SO, WO, ST and WT. However, if the Enterprise A, as a large project contracting enterprise, adopts a defensive strategy in face of the golden opportunity of the current strategy of "Belt and Road Initiative", it would be difficult to meet the development demand of the enterprise.

The Enterprise A has rich experience in the construction of municipal infrastructure construction, and the important construction content of the strategy of "Belt and Road Initiative" is infrastructure construction. Therefore, the strategic goal of the Enterprise A in the next phase is to go abroad, with the countries along "Belt and Road Initiative" as its major direction of market expansion. In addition, the Enterprise A needs also to work out pertinent improvement schemes against the problems faced by the enterprise in overseas construction projects, so as to undertake and administer the construction projects in countries along "Belt and Road Initiative". Therefore, the Enterprise A defines its strategy in the next phase to be ST multi-operation strategy and WO torsional strategy at the same time, namely, vigorously developing the diversified model of project contracting, e.g. EPC, PPP. Against the HSE management defects and shortcomings faced in the current management of overseas construction projects, the Enterprise A needs to establish a perfect HSE management system as soon as possible, so as to meet the requirement of undertaking projects in countries along "Belt and Road Initiative", explore the international market, and promote the international image of the enterprise.

3.3.2 Analysis of strategic goals

Against the above-mentioned strategic planning, the Enterprise A proposes that it should adhere to the sustainable development idea of "advocating green, people first, paying attention to coordination, and boosting sharing", adapt to the new trend of sustainable development, firmly grasp such development opportunities as "Belt and Road Initiative", national new-type urbanization, the Economic Belt of the Yangtze River, Chengdu and Chongqing Economic Belt, sponge city and smart city construction, optimize industrial structure, operation mode, business structure and market layout, innovate the project management model and operation contracting model, adhere to the coordinated development of reform and innovation, intensify the construction of project management team, and try to, by 2020, become a large state-owned comprehensive project contracting enterprise with an optimized governance structure, normalized operation and management, outstanding main business, a large scale of other industries, a strong sustainable profitability, a good financial status, a modeling ability of fulfilling social responsibility and an outstanding capacity of sustainable development.

With regard to operation goals, the Enterprise A has further worked out its operation goals in the forthcoming five years, namely, trying to be a project contracting enterprise oriented to management and efficiency with overseas influence and nationwide reputation. In 2015, the base figure of contract amount was RMB 3.3 billion, the operating revenue was about RMB 2.9 billion, the profit was about RMB 40 million, and the operating profit margin was 1.3%. The enterprise will try to achieve a market agreement-signing amount of RMB 5 billion, an operation revenue of RMB 4 billion, a profit of RMB 80 million and operating profit margin of 2% by 2020 respectively.

With regard to operation model, the Enterprise A will further adjust its industrial structure, try to be an enterprise oriented to quality and efficiency, do the traditional main business well (including mechanical and electrical installation, and municipal infrastructure construction), gradually extend its business to manufacturing, service, investment, financing, etc., create diversified profiting models, and shift its project contracting models gradually to PPP, EPC and other current mainstream models, and initially become an enterprise of diversified coordinated development in which the scale of main business accounts for 70% with a profit of about 60%～70% and the scale of manufacturing, service and investment accounts for 30% with a profit of about 30%～40% within five years. In the forthcoming five years, due to the influence of the external environment, along with the decrease of industrial projects, the undertaking percentage may decline somewhat, and the enterprise will gradually raise its undertaking percentage of mechanical and electrical installation works of civil projects. By 2020, the enterprise will try to raise the percentage of its business volume of the industry of engineering construction to 80% of the total business volume; therein, the traditional municipal infrastructures will account for more than 60%.

The major strategy for the next-step development of the enterprise is expanding the operation of the enterprise and forming a complete industrial chain and supportive service. With regard to the model of project contracting, the enterprise will develop gradually toward such models as EPC and PPP. With regard to industrial structure and contracting models, the enterprise will try to achieve double diversified development. In the current main business of project contracting, the enterprise will focus on the following two industries:

(1) Manufacturing. The enterprise will exert the resource advantage of its processing base. In addition to the traditional non-standard equipment processing and manufacturing, maintenance, etc., the enterprise will gradually invest in and build up a supportive production line of carriages with a certain scale and production capacity, and create a domestically first-class base of prefabrication, production and processing. In the forthcoming five years, centering around processing, manufacturing and sales, the enterprise will form its characteristic products, e.g. supportive carriages, containers, standardized products of civilized construction site, etc.

(2) Service industry. The current construction projects have a larger and larger scale and higher and higher technological content, especially in the case of the technological content of electromechanical equipment. The project contracting enterprises urgently need to innovate the management mode and means, especially in improving the perfect rate of mechanical and electrical equipment, reducing the equipment accident rate, reducing the maintenance cost, and realizing the safe and stable operation of the equipment. The traditional human-focused operation and management model of electromechanical equipment has such problems as large input and a lot of wear and tear. If any problem arises, the support of effective data is often absent, which would again result in such problems as insufficient and untimely repair and protection. In particular, with regard to densely-populated construction projects of municipal infrastructure, insufficient management would probably bring about serious consequences. Against these problems, the Enterprise A is studying and developing “the housekeeping information management system of electromechanical equipment” with the help of the technology of Internet of Things. By 2020, the business volume of electromechanical equipment repair and maintenance and other service industry will have reached 5% of the total volume.

With regard to the layout of strategic regional markets, the Enterprise A will gradually intensify its expansion of domestic and overseas markets on the basis of deepening urban markets, forming the model of “4-3-3”. In particular, the Enterprise A will spare no effort to expand the markets in countries along “Belt and Road Initiative”, trying to hereby gradually stand firmly in overseas markets. In 2015, the business scale of the enterprise accounted for 30.97% of the local market, 64.03% of the domestic market, and 5% of the foreign market. By 2020, the enterprise will try to achieve a ratio of 4:3:3 among the project contracting amounts of the local, domestic and overseas markets.

On the other hand, at the next step, the Enterprise A will focus on innovating the models of its project contracting, reinforce its cooperation with design institutes, financial institutions and large investment development companies, set up a strategic partnership with them, and jointly explore target markets with them. Current mainstream models of project contracting including PPP and EPC are the key direction of the future development of the enterprise. By integrating social resources, by means of association, the enterprise will energetically boost the cooperation of PPP and EPC projects and try to reverse the situation of poor profitability of construction models, and try to make the percentage of PPP and EPC model construction projects of the company reach about 20% of the total scale by 2020, reinforce capital operation and investment management and lever the market via capital operation and investment. In the forthcoming five years, the enterprise will acquire projects by emphatically cooperating with design institutes or exploring such modes as share controlling, participation and purchase. With regard to projects with a large profit margin and difficulty in receipt of project settlement fund, the enterprise will solve this problem by converting project fund into shares to participate in profit or serve as assets.

Boosting refined management, and accelerating the popularization of BIM technique and CCM cost technique in projects. At present, the construction project has entered the period of "fine management". The enterprise tries to promote the fine management in the form of "setting an example for others to follow", and realizes the project management requirement through the "fine management" of the key point of the project construction. In the forthcoming five years, the enterprise will incorporate the quality, progress, safety, cost, etc. of projects into BIM, CCM and other techniques, and earnestly analyze, compare, evaluate and summarize the actual consumed amount and planned consumed amount and construction drawing budget amount of materials. In the forthcoming five years, the enterprise will achieve industrialized, information-based, automatic and intelligent management over industrial production, enhance the quality and efficiency of industrial production management and boost the model of industrialized, information-based, automatic and intelligent management over industrial production.

3.4 Analysis of enterprise weaknesses

In order to attain its strategic goal of sustainable development, the enterprise should ensure that its project portfolios, project sets and single projects conform to its organizational strategy or are determined by its organizational strategy. Therefore, the enterprise needs to set up a perfect management system of projects at the organization level (PMO), enabling all layers of the organization to understand the strategic plan and goals of the enterprise. PMO achieves organization value decision-making through project portfolio management, completes the resource coordination and relation control among single projects through project set management, completes achievement delivery through project management and attains the set goal of project set management, and then realizes commercial value through operation and attain the strategic goals of the enterprise. Therefore, as a basic and important part of organizational project management system, project management involves comprehensive governance and improvement.

The above-mentioned SWOT analysis indicates that, the Enterprise A has a problem with property management, and particularly has an outstanding problem with HSE management. The detailed analysis is as follows:

(1) Lack of a perfect HSE management system. One of the main objectives of "The Belt and Road" strategy is to strengthen the infrastructure construction in the countries along the belt and road by utilizing the rich experience of Chinese project contracting enterprises in the construction of infrastructure, so as to promote the Chinese enterprises to enter the international market. From the analysis of SWOT, the foreign project construction experience of Enterprise A is a little insufficient, and it lacks the ability to deal with the risk of environment and so on. Although Enterprise A has undertaken some foreign construction projects and initially constructed HSE management system, its HSE management system is too rough to meet "green and fine" management requirements of the current construction project. In order to meet the development requirements of the engineering construction industry and boost sustainable development and ecological civilization construction, the enterprise needs to set up a perfect system of HSE management.

(2) Lack of a supportive method of performance evaluation of HSE management. When compared with industry benchmarking enterprises, the enterprise lacks quantitative analysis tools. In order to further improve its HSE management level, the enterprise needs to study the corresponding evaluation methods of management performance.

(3) Lack of a perfect comprehensive evaluation system of project efficiency. In its strategic planning, Enterprise A has put forward the sustainable development concept of "green, people-orientation, coordination and sharing" in the next stage. However, at present, the enterprise lacks an effective HSE management system and management performance evaluation method, so that the project efficiency level cannot be quantified correctly, including environmental protection and other indicators of sustainable development capacity.

3.5 Summary of this chapter

This chapter compares the Enterprise A with a benchmark enterprise in the industry, analyzes the strengths and weaknesses of the Enterprise A in the context of the strategy of “Belt and Road Initiative”, and analyzes the strategic goals and plans of the Enterprise A with the SWOT method. In order to achieve the idea of sustainable development of “advocating green, people first, paying attention to coordination, and boosting sharing” proposed in the strategic goals of the Enterprise A, the enterprise must perfect the corresponding organization and management system. Therefore, according to the development situation faced by the enterprise at present and the establishment requirement of the organization-level project management system of the enterprise, this chapter points out the weaknesses of the enterprise in its present project management after due analysis, chiefly including the following aspects: lack of a perfect HSE management system, lack of supportive evaluation methods of HSE management performance, and lack of a perfect comprehensive evaluation method of project efficiency, providing an idea for the further research in the following parts of the dissertation.

Chapter 4: Analysis of Project HSE Management at the Organization Level

According to the above analysis, combined with the characteristics of the Enterprise A and construction projects as well as expert opinions, this chapter sets up the HSE management system at the organization and project levels, and proposes that the organization-level HSE management system should serve as the HSE management outline, and the project-level HSE management system as the implementation rules of HSE management.

4.1 Data sources

4.1.1 Interviewees

From May to October 2015, I conducted an in-depth investigation and analysis of the difficulties facing the Enterprise A in HSE management. A total of sixteen experts were invited, and all of them met the following two conditions: 1) All were middle and senior managers or engineers of this enterprise; 2) They had more than 10 years of experience in the field of construction project management. As shown in Table 4-1, Experts I ~ V were the managers of the Enterprise A; Experts A ~ K were project managers, with certain authority and pertinence. Based on the opinions of these experts, the implementation outline of organization-level HSE management system and the implementation rules of project-level HSE management system were designed respectively.

As can be seen from Table 4-1, the experts selected worked for 25.56 years and aged 48.38 on average. They were senior managers of enterprises or large construction projects, with rich experience in the implementation of business or project management. Questions raised by these experts could basically fully reflect the existing problems of HSE management, and their suggestions could provide a practical way to improve HSE management.

Table 4-1 Basic information of interviewed experts

No.	Position	Position /title	Specialty	Education background	Years of working	Age
Expert I	Deputy GM of the Enterprise （Head of HSE）	Deputy GM	Safety Engineering	Postgraduate	20	46
Expert II	Head of Contract Management of the Enterprise	Head	Project Cost	Undergraduate	21	42
Expert III	Head of Operation Management of the Enterprise	Head	Civil Engineering	Undergraduate	25	48
Expert IV	Head of Engineering Technology of the Enterprise	Head	Structural Engineering	Undergraduate	22	44
Expert V	Head of HSE Management of the Enterprise	Head	Safety Engineering	Junior college student	30	50
Expert A	Project Manager	Senior Engineer	Safety Engineering	Junior college student	35	55
Expert B	Deputy Project Manager	Senior Engineer	Civil Engineering	Postgraduate	23	48
Expert C	Chief Project Engineer	Senior Engineer	Municipal Engineering	Junior college student	25	46
Expert D	Deputy Project Manager	Senior Engineer	Architectural Engineering	Undergraduate	28	50
Expert E	Deputy Project Manager	Intermediate Engineer	Structural Engineering	Undergraduate	26	49
Expert F	Project Manager	Senior Engineer	Environmental Engineering	Undergraduate	22	45
Expert G	Project Manager	Senior Engineer	Structural Engineering	Postgraduate	21	47

Expert H	Deputy Project Manager	Senior Engineer	Architectural Engineering	Undergraduate	29	52
Expert I	Chief Project Engineer	Senior Engineer	Municipal Engineering	Undergraduate	25	49
Expert J	Project Manager	Senior Engineer	Civil Engineering	Undergraduate	27	50
Expert K	Project Manager	Senior Engineer	Civil Engineering	Undergraduate	30	53

4.1.2 Interview content

To make a comprehensive analysis of the weaknesses facing the Enterprise A in project management, I invited the aforementioned 16 experts from the Enterprise A and carried out all-around communication, mainly dicussing the development trend of construction industry, development direction of management and project management level of the Enterprise A, and analyzing the weaknesses existing in the enterprise project management based on the data collected from the Business Management Department, Engineering Technology Department, HSE Management Department and other departments, so as to offer reasonable suggestions for optimizing the project management level of the Enterprise A. Specific contents of interview are described below.

4.2 Project management problems existing at the organization level

Although the Enterprise A has yielded fruitful results in the past period, and can basically realize the goal of business operation and project management, along with the rapidly changing situation in the engineering construction industry both at home and abroad, the engineering construction industry has gradually developed towards "greening and refinement" management. Problems that still need to be solved by the Enterprise A include:

The external environment facing the enterprise is not optimistic. In recent years, the share of the enterprise in the traditional advantage market has gradually shrunk, labor costs have also increased quickly, any the difficulty in recovering project funds still exists, all of which have led to the deterioration of cash flow, intensification of industry competition, and increasing deterioration of external environment of the industry.

The management's awareness of market expansion has not completely changed. Some corporate management personnel are satisfied with the current scale and reputation of enterprise development, and think that as long as the main business of engineering construction is well carried out, the everlasting prosperousness of the enterprise can be ensured. Moreover, they also become accustomed to the past mode of management by administrative order, and are content with the completion of basic tasks, lacking a high sense of responsibility. Being satisfied with coping with superior leadership and specific affairs, they fail to focus on improving their own technical ability and management ability, and lack creativity, initiative and innovation spirit at work.

The adaptabilityof the enterprise to the market can hardly match the needs of its development. The corporate management is still lacking in the capabilities for market control, risk assessment and crisis management, etc. and their scientific decision-making ability needs to be further improved. Their capabilities for the organization and coordination of large-scale construction projects, as well as for project cost control management involving business material procurement and labor subcontracting remain to be improved, and the labor productivity does not match the enterprise scale.

The organizational and production capacity of the enterprise is still to be optimized. There is a scarcity of excellent project management personnel, comprehensive talented people familiar with domestic and foreign projects, technicians proficient in design, skilled technical workers and other human resources. With project construction as the main business, the enterprise has not formed a diversified business pattern. Due to a single product structure, the risk resistance capacity of the enterprise needs to be strengthened.

The HSE management system is not perfect enough. At the present stage, China's construction projects tend to pay attention to safety management without much attention to occupational health and environmental management, lacking the consciousness of actively accepting and fully implementing HSE management. Although the Enteprise A has undertaken some foreign construction projects and preliminarily built the HSE management system, its HSE management system is too rough, and hard to meet the current "greening and refined" management requirements of construction projects, the deails of which are shown as follows:

(1) Lack of HSE management feasibility study, and no clear-cut HSE management objectives; specifically, lack of investigation on HSE management in the feasibility study report

of project construction application, and lack of scientific demonstration of urban ecology and landscape destruction.

(2) Unadvanced HSE technology and unsystematic management system. During project management, large-scale engineering project contracting enterprises in our country are often shown as: The concepts of occupational health and environmental management are just at the beginning; risk identification, risk analysis and assessment, as well as risk management techniques in the aspects of occupational health and environment management are weak, failing to eliminate the root cause from the identification stage.

(3) The lack of awareness of HSE management, the existence of fluke mind among project managers, the poor operability of all kinds of safety & health and environmental management system; the HSE management assessment is not in place, and the concept of "people-oriented" is not implemented throughout daily production activities; moreover, first-line workers of construction projects are mostly migrant workers, whose cultural quality and right-safeguarding awareness are not high, which is not conducive to the full participation in HSE management.

(4) HSE management becomes a mere formality. For the owner of construction projects, economic benefits and profits can be exerted and obtained only when project deliverables have been put into use. Therefore, the owner often pays the most attention to project progress and quality. In case of any contradiction between project progress and quality, the owner neglects the contractor HSE management, and in order to obtain more economic benefits, the contractor also often ignores HSE management requirements, thus making the contractor HSE management become a mere formality.

(5) The evaluation mechanism of HSE management is not perfect. Although leaders of the Enterprise A attach importance to project HSE management and emphasize the importance of HSE management, they have not yet constructed a set of scientific HSE management evaluation methods, which makes it difficult to evaluate the project HSE management. At the same time, the enterprise lacks an incentive mechanism.

(6) The HSE factor is not considered in the Enterprise A's current project efficiency evaluation, which focuses on the "three goals" of quality, schedule and cost. When "three goals" conflict with HSE management, in order to attain the "three goals" to the maximum, the project level often ignores the HSE management objectives.

4.3 Establishing the project HSE management system objectives at the organization level

In order to ensure that the diversified economic strategy and reverse strategy of the Enterprise A can be effectively implemented, and at the same time considering high requirements and high standards of foreign construction engineering project for HSE management, it is imperative to build a systematic HSE management system, with its main objectives as follows:

(1) In the aspect of enterprise business development, foreign engineering projects attach great importance to HSE management, and the establishment of a sound HSE management system is the foundation for contracting foreign construction projects. When the construction unit selects the project contracting unit, the HSE management ability is an important indicator to measure the management ability of the project contracting unit. It will be difficult for contracting enterprises without a perfect HSE management system to undertake foreign construction projects.

(2) At the corporate social responsibility level, the establishment of a sound HSE management system is a good embodiment of CSR performance. A sound HSE management system has an important positive effect on occupational health, safety and environmental management, and serves to promote the construction of ecological civilization and realize the sustainable development of enterprises and society.

(3) At the employee level of the enterprise, the HSE management system integrates the occupational health and safety of employees into the strategic height of the enterprise, which is conducive to improving the sense of belonging and ownership of employees, promoting the establishment of good relations between employees and the enterprise, and enabling the common development and prosperity of employees and the enterprise.

4.4 Establishing the project HSE management system structure at the organization level

In order to comprehensively build an organization-level project HSE management system, the Enterprise A should set up an HSE management organizational structure at the organization level and the project level. At the organization level, the HSE Management Department directly led by General Manager should be set up; at the project level, the HSE management team should be set up under the direct leadership of the organization-level project HSE Management Department, and be responsible for the full implementation of HSE management implementation rules at the project level. The organizational structure of HSE management is shown in Figure 4-1.

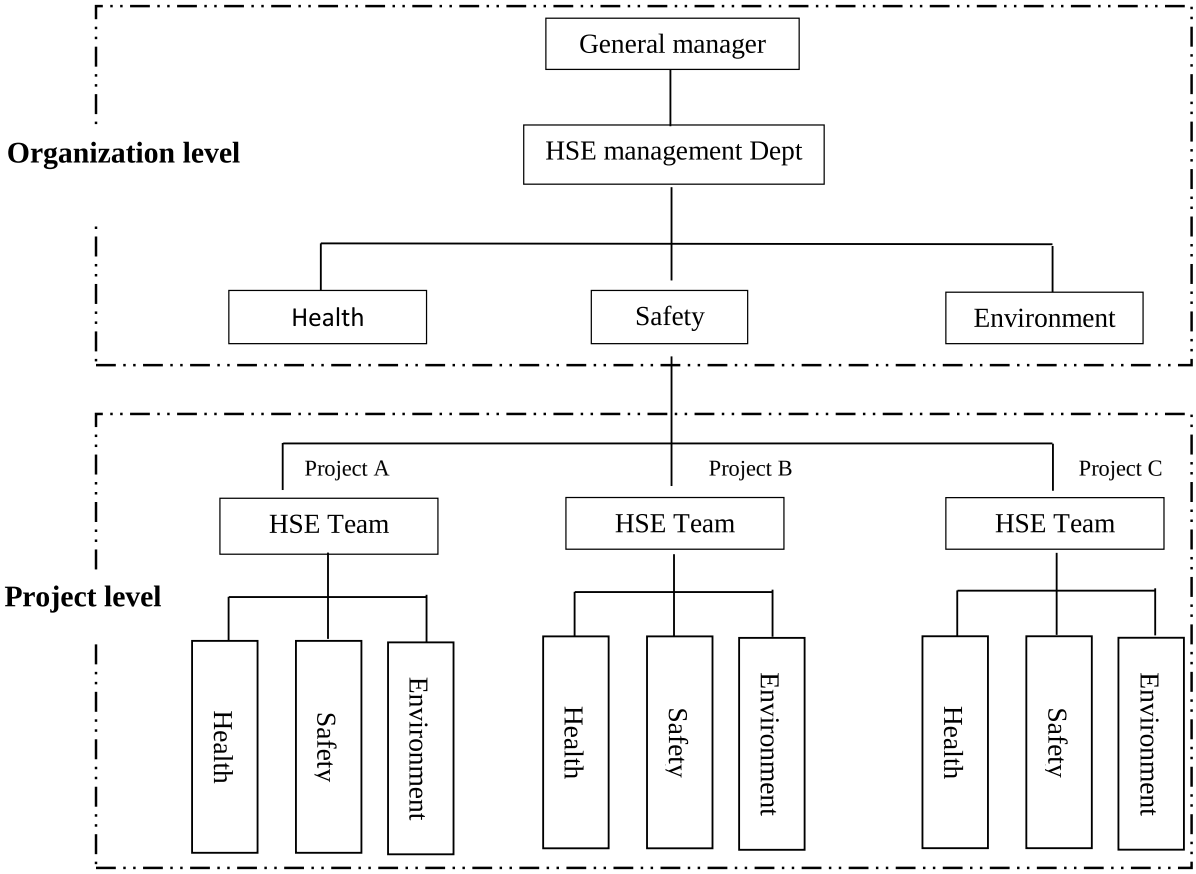

Figure 4-1 Organizational structure of HSE management

4.5 Project HSE management outline at the organization level

In view of the above problems facing the Enterprise A during HSE management, the Enterprise A organized expert discussion, including senior managers of foreign construction projects. The interviewed experts held the opinion that the HSE management outline should be set up in the following three aspects.

4.5.1 Occupational health control measures

Experts held the opinion that regular occupational health examination should be carried out for the important positions of the Enterprise A, specifically shown as follows: The enterprise labor union should, assisted by the HSE Management Department, organize the health examination for organization-level management personnel on an annual basis; for the employees at the operation level, the scope of employees and time limits for occupational health examination should be defined according to the operation post and work conditions, and health examination should be organized at least semiannually. For workers exposed to a toxic and harmful environment (including painters, welders, flaw detectors, car repairmen, etc.), as well as catering service staff or public life logistics facilities operators, cooking staff, with their cumulative working time reaching 250 days, and those engaging in special operations with their cumulative working time reaching 500 days, the routine health examination is conducted once every two years. For those engaging in the general work, not within the above scope, with their cumulative working time reaching 750 days, the routine health examination is conducted once every three years. In addition to routine examination, when the above operators feel unwell, they should receive health examination at any time. After the approval of the enterprise leadership, the daily health examination should be conducted and the specific requirements specified by the project level HSE management rules.

The Project Department should reasonably arrange the working hours of the workers during the period of high temperature weather, formulate and implement the measures for preventing heat and lowering the temperature, rationally adjust the working hours, provide sufficient heatstroke drugs that meet the hygienic standards, free of charge, to workers engaged in open-air work and indoor high temperature work during the high temperature season., etc., set up a resting place according to local conditions, adjust their work place or work position during the period of high temperature weather for workers whose physical condition is not suitable for high temperature weather, and for those engaged in open-air work or indoor high temperature work, formulate prevention measures to deal with the sudden diseases, strengthen the supervision and management of occupational health according to the standards of quality, environment and occupational health and safety management, strengthen the publicity of prevention knowledge of regional high-incidence diseases of the project, carry out preventive measures and emergency plans in advance, publicize the prevention and curing measures of occupational diseases and epidemic diseases through board newspaper, propaganda column and so on, provide necessary labor protection articles to the workers and staff, and regularly organize the workers to receive occupational health checkup to maintain the occupational health and safety.

4.5.2 Safety management and control measures

In light of the project management experience, and after in-depth discussion, experts think that safety management should be emphatically carried out by categories. The implementation rules of project-level HSE management should fully consider the above personal injuries and health damage that may occur, formulate detailed management implementation rules. The organization-level project HSE Management Department should organize other functional departments to identify the factors that may lead to safety accidents according to the characteristics of the facilities and equipment in the work place of each department.

At the project level, the perfect labor protection supervision system and management rules should be established, opinions from the staff and worker collected, safety inspection regularly carried out, safety problems, major accident risks and occupational hazards existing during inspection recorded, supervision and rectification tracked, and meanwhile HSE knowledge well publicized, so as to make the staff and workers actively assist the administrative department to carry out the inspection of safety in production and actively organize regular safety inspection, for example "4-level" safety inspection by quarter, month, week and day.

The Safety Production Department of the enterprise should, at the beginning of the HSE management system construction, unite functional departments and the Project Department to carry out hazard identification and risk analysis, to ensure that all departments have a certain knowledge of major hidden hazards and occupational hazards. Reidentification should be organized in the following cases: any change made to relevant laws and regulations, the occurrence of major environmental and occupational health and safety accidents and emergencies, the start-up of the new project undertaken by the enterprise, any modification of production process, product or service, as well as any complaints received from customers and interested parties and so on.

4.5.3 Environmental pollution management and control measures

The HSE Management Department should organize functional departments and the Project Department to identify any possible adverse effects on the environment according to department activities, product and construction processes, such as any environmental impact of enterprise activities on the enterprise, surrounding residents and regions, and any past, present or future potential environmental impact of the enterprise, as well as any environmental impact of the enterprise under different production conditions, etc.

The HSE Management Department and the Project Department are responsible for the evaluation of the identified environmental factors, which should take into account such four factors as the possibility of environmental impact (m1), the possibility of occurrence / prevention (m2), the degree of environmental impact (m3), and accident / complaint (m4). The importance of environmental management is determined according to the results of the above four factors, that is, the value of evaluation factors ($d=m1+m2+m3+m4$). If there is any violation of laws and regulations in the activities, products or services of the enterprise, the environmental factor needs to be evaluated as above and directly regarded as an important environmental factor.

The results of environmental assessment are recorded in real time by HSE Management Department and Project Department. The higher the value of evaluation factor, the greater the impact on environment. If the value of an evaluation factor exceeds a certain limit, the environmental factor can be regarded as an important environmental factor, and should be marked in the environmental factor identification and evaluation table and recorded in the list of important environmental factors. According to the actual situation of the project, the evaluation factor is jointly set by HSE Management Department and Project Department.

The HSE Management Department and Project Department should keep real-time recording of environmental assessment results. If the evaluation factor exceeds a certain limit, it can be recorded in the list of important environmental factors. The evaluation factor should be set by the HSE management department and the Project Department together according to the actual situation of the project. The HSE Management Department and Project Department should ensure that the formulation of the management plan embodies the control of important environmental factors, or important environmental factors are controlled by formulating relevant measures including procedures, operation instructions and emergency plans, and the relevant departments and Project Department are organized to implement these measures.

The HSE Management Department should, at the beginning of the establishment of the HSE management system, organize various functional departments and the Project Department to conduct environmental factor identification and evaluation. In the case of any change made to laws and regulations related to environmental factors, the occurrence of major environmental accidents and emergencies, and the startup of new projects undertaken by the enterprise, etc., timely reidentification and updating should be carried out.

All employees in the enterprise should participate in training, continuously improve their HSE management awareness, and clarify prevention and control methods. The unacceptable risk should be controlled. The control methods mainly include such three approaches as management scheme, operation control and emergency plan, and the effect of implementation should be supervised to ensure effective implementation. When control measures are determined or changes to existing controls are considered, risk reduction should be considered in the following order: elimination, substitution, engineering and technical control measures, warning or management control measures, personal protective equipment, etc.

4.6 Project HSE management rules

4.6.1 HSE management plan

Project Manager should be chiefly in charge of HSE management at the project level, plan and set up the HSE management team. The team leader of the HSE management team is Project Manager. The team members should include Deputy Project Manager, Chief Engineer, Safety Engineer, Quality Control Engineer as well as other department heads and professional technicians. The HSE management team should be solely responsible for the project HSE management.

The Project Management Department should, according to the actual situation of the project, formulate the project HSE management rules, and require all staff members to fully carry out the HSE management in strict accordance with the HSE management rules. The HSE management rules should be established mainly in the aspects of HSE management consciousness of all the participants, the rules and regulations that staff must abide by, safety procedures, risk assessment, and the special deposit to be set up for HSE management.

4.6.2 HSE management education and training

HSE education and training is one of the important measures for the effective management of HSE. The management of the Project Management Department should, in accordance with the requirements of project management and the provisions of national laws, provide training and do well in training registration records, so as to ensure that employees have sufficient HSE management consciousness and knowledge. Training contents should include working practices, personal HSE management requirements and behavior standards, important requirements for HSE management rules, HSE hazard report procedures, emergency handling procedures after the occurrence of HSE issues, investigation and post-processing procedures of HSE issues, as well as rewards and punishment for HSE issues, etc. At the end of each training, trainees should be evaluated and inspected, e.g. organizing the examination, competition and field practice, etc. of HSE management knowledge, so as to guarantee that everyone can understand and master the HSE management knowledge taught during training.

4.6.3 HSE inspection

The HSE management inspection in the Project Department can be classified into four types: monthly inspection, weekly inspection, daily inspection and special inspection according to the specific inspection time. The main contents and related requirements of each inspection are described as follows.

Daily inspection: using job observation cards for real-time recording, including hazards, and unsafe acts identified, as well as the situation of unsafe acts and corrective actions, including equipment operating mode, hoisting methods, and the use of personal safety supplies and so on.

Weekly inspection: The inspection team must find any place and environment that may result in accidents or potential safety hazards, as well as any behavior of neglect or violation of HSE management requirements, and require immediate rectification. The contents of inspection should include emergency equipment and operating procedures, as well as identification of harmful substances and other chemicals.

Monthly inspection: monthly comprehensive summary of HSE management of the project, as well as analysis of the results achieved in HSE management of the current month, existing deficiencies and measures to be taken at the next step. The contents of monthly inspection should include the execution of the project HSE leading group, as well as the compliance of construction personnel with the on-site safety rules, regulations and procedures, etc.

Special inspection: The targeted special inspection should be organized by the HSE management leading team according to the condition of HSE management at the project construction site, such as special inspection of waste water treatment.

4.7 HSE management incentive mechanism

In order to motivate project members to actively participate in and implement the HSE management measures in an all-round way, feasible rewards and punishment measures should be formulated, and project managers urged to effectively manage the HSE through rewards and punishment.

For those who severely violate the HSE management provisions, the principle of "three zero-tolerances" should be adhered to. Such violations mainly include: Safety belts are not tied at 100% while working at heights or personal anti-falling measures are not implemented; confined spaces are entered for operation without permission or without safe measures implemented, etc.; for those responsible for other hidden dangers of violation, onsite education should be conducted for the first time and re-education & re-training be carried out for the second time, and they should be cleared out of the project for the third time.

With regard to the punishment over the persons responsible for other hidden dangers of violation, the first general hidden danger of violation should be marked on their pass and recorded on their electronic file and on-site education should be offered to them; the second general hidden danger of violation should be again marked on their pass and recorded in their electronic file, and the training, education and examination should be offered again to them; in case of the third general violation, the persons in charge should be dismissed from the project, their pass should be recovered, and they should be no longer allowed to access the project scene.

The Project Management Department will provide HSE management incentive funds. The project HSE management team will develop the HSE management performance evaluation system, and give out bonuses to units or departments with good HSE management performance. The reward should be provided as follows: awarding functional departments or subcontractors ranking the top two in the monthly evaluation and with an evaluation score of more than 85 points, and timely awarding field personnel with good performance.

With regard to project HSE accidents due to the subcontractor's reason, in addition to the related legal responsibility according to law, the Project Management Department will pursue the subcontractor's liability for breach of contract, and impose corresponding punishment, e.g.: deducting the project payment of RMB 1 million for each death, and requiring the subcontractor's project manager to immediately leave the construction site and disallowing his reentrance.

The deductible HSE margin should be borne by the subcontractor, and the subcontractor may not transfer it directly or indirectly to the responsible person. However, the subcontractor may punish the responsible person according to the internal management system. The employees of the Project Management Department at all levels as well as the HSE management team, and the supervision company can propose the deduction of the HSE margin, and the relevant person should be the proposer. The proposer should inform the HSE management team of the reasons for the deduction of the HSE margin and fill out the Violation Hidden Danger Deduction Notice. The HSE management team leader of the Project Management Department or its authorized person should review the Violation Hidden Danger Deduction Notice, and finally make a decision whether to deduct the HSE margin.

4.8 Summary of this chapter

This chapter first introduces the relevant content of expert communication within the enterprise, mainly including the situation description of the communication object and the dilemma facing HSE management. Secondly, based on the problems existing in the HSE management, the HSE management department is set up at the organization level, the HSE management team set up at the project level, and two levels of HSE management system put forward - organization-level HSE value choice and project-level HSE implementation requirements. Finally, reward and punishment measures for HSE management are given. It provides a basis for the design of the HSE management system, as well as a guarantee for the effective implementation of the HSE management system.

Chapter 5：HSE Management Performance Evaluation Methods of Construction Projects and Their Application

In the last chapter the organization-level project HSE management system is constructed at the organization and project levels. To compare and analyze implementation effects of the project HSE management system, the HSE management performance of the project needs to be evaluated. Therefore, this chapter discusses the evaluation methods of HSE management performance. Eight typical projects contracted by the Enterprise A are selected as the research object. First, through expert interview method and combined with the existing literature, the HSE management performance evaluation indicator is established; then the HSE management performance of eight projects is analyzed by use of Analytic Hierarchy Process; last, evaluation results are analyzed and suggestions for improving HSE management performance put forward.

5.1 Overview and characteristics of the project undertaken by the Enterprise A

As a large engineering project contracting enterprise, the Enterprise A is mainly engaged in contracting large-scale chemical engineering projects, construction projects and municipal engineering projects. These project models are huge, and the project contract prices are more than RMB100 million. This study chooses the typical project A as an example and expounds its overview and characteristics, and the other projects have similar characteristics.

5.1.1 Overview of the Project A

As a provincial key construction project, the Project A can produce 1.3 billion cubic meters of natural gas per year after being put into operation. With the contract price of RMB720 million and the accumulative project duration of 12 months, this project is the first large-scale comprehensive chemical project undertaken by the Enterprise A. This project roughly contains the coal preparation system, gasification slag water, purification transformation, compression, air separation, boiler power generation, battery limit utilities, sewage station and water treatment, as well as pipe rack, outer tube and exterior line installation composition, etc. in new and old plant areas.

In the short term, the undertaking and implementation of the Project A are a support for the completion of production tasks by the Enterprise A from 2014 to 2015. However, from the point of long-term development of the enterprise, it represents an expansion of the business scope of the enterprise, and its solid performance in the large coal chemical industry. Moreover, through the implementation of the project, the comprehensive management ability of the enterprise is enhanced, and at the same time a large number of chemical project construction technical management personnel are cultivated, reserving useful talented people for the development and expansion of the enterprise. In the process of project implementation, we have also found deficiencies: insufficient reserve of labor assignment resources (especially highly skilled special types of work understaffed), and the deepening of large project management mode, etc., all of which deserves discussion and improvement.

Due to the large workload and the above characteristics of the Project A, in order to smoothly complete each task, the project management team are under unified command of Project Manager. Moreover, 7 functional departments including Comprehensive Department and HSE Management Department have been set up to fully manage 7 production departments.

Due to the large scale and wide coverage of the project, the Management Department adopts the strong matrix organization structure. Specifically, professionals transferred from the department accept the leadership of Project Manager and Department Manager at the same time; in case of any conflict in the leadership between them, the leadership of Project Manager should prevail. Through such organization structure, the strengths of all departments can be concentrated for project implementation. Participation in and monitoring of the whole process of the project by each department of the enterprise reflect the strategy of "Making concerted efforts in doing great things". Project-based organizational structure is adopted at the project level, as shown in Figure 5-1 and Figure 5-2.

5.1.2 Characteristics of the Project A

The Project A is mainly composed of 11 devices (systems), including coal preparation system, gasification slag water device, purification transformation device, compression device, air separation device and boiler power plant, etc. The functions of each device are different, but complementary, forming interconnected systems engineering to jointly produce qualified natural gas. The Project A has the following characteristics:

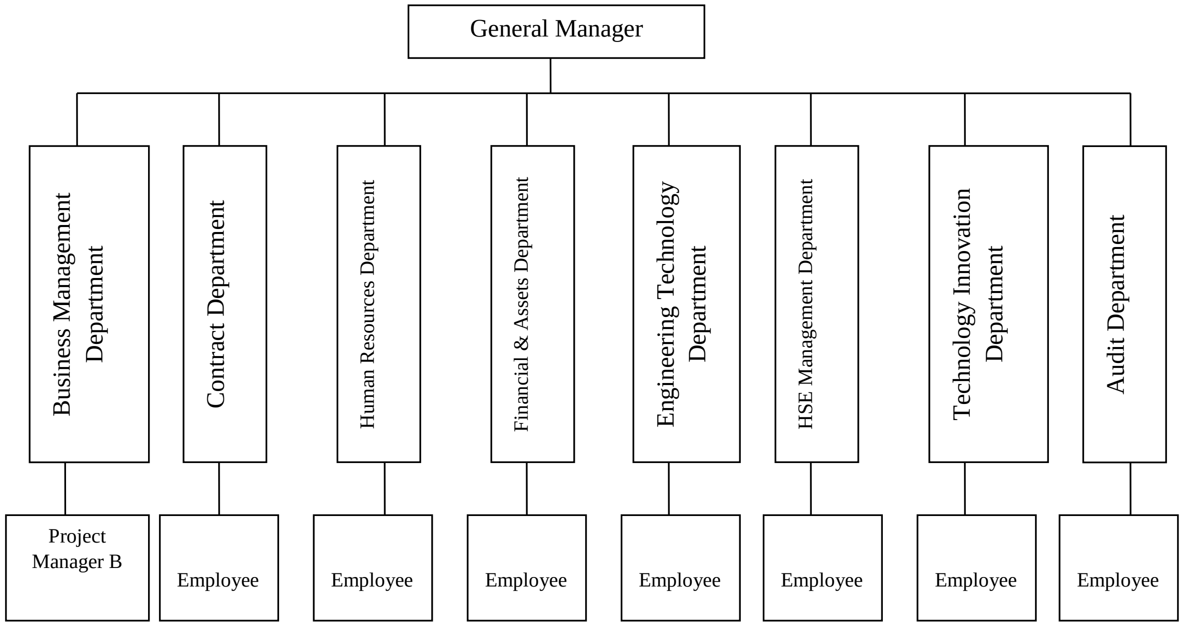

Figure 5-1 Strong matrix organization chart of the Project A

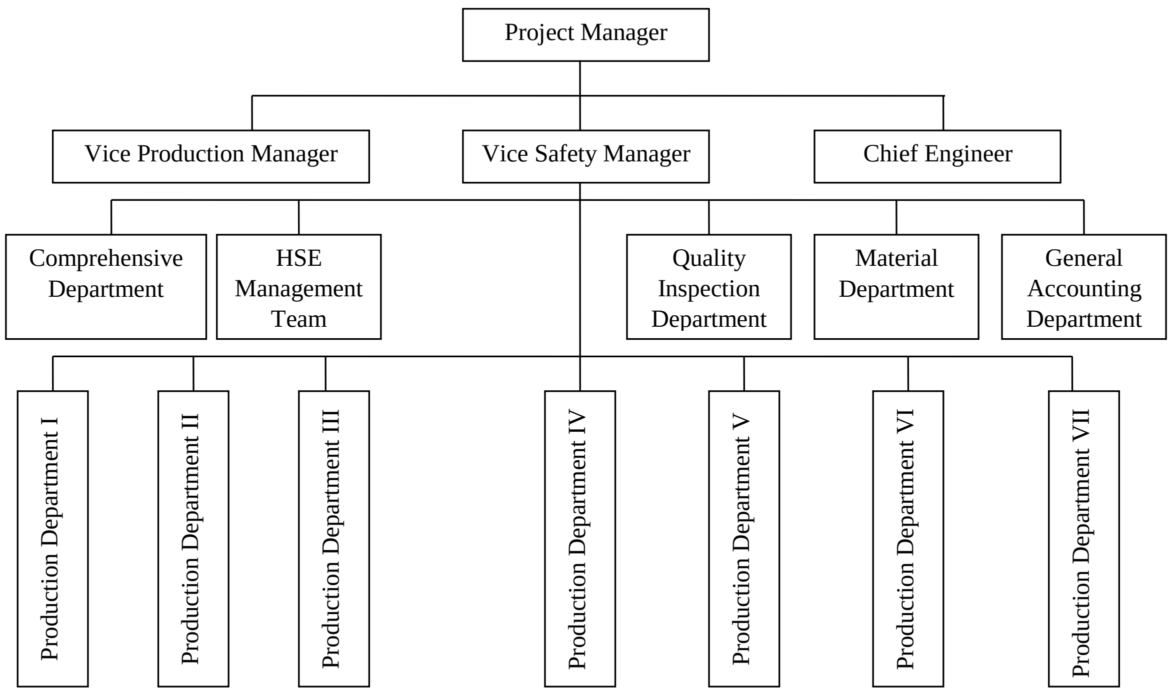

Figure 5-2 Project-based organization structure

1. The core technology involved is complex and quality requirements are strict.

The core main equipment of this project is comparatively complex in technology, with a high degree of automation. It has high requirements for the installation technology, construction methods and measures of process pipelines, electrical instruments and DCS systems. Moreover, precision and advanced rotating equipment and various kinds of tower equipment put forward more strict control and specifications for the installation & debugging technology and hoisting mode.

2. Due to heavy and diversified equipment to be installed, transportation and hoisting work is very difficult.

In the installation work of this project, there are many kinds of large-tonnage equipment. Therefore, it is very difficult to transport and hoist the equipment. In the process of construction, the approach and installation sequence of equipment must be reasonably arranged.

3. Civil engineering is large in quantity but scattered in complex and diverse forms, with high architectural structure as well as broad distribution points, so it is the main link that affects the progress of the project. In addition, except that 6 silos are put together to produce a large construction volume (about 90 million), all civil engineering projects are small in individual project volume, and bent frames are large in individual project volume (such as pipe racks and transfer stations, etc.), thus bringing about numerous adverse factors to the cost control of civil construction.

4. This project needs many types of special equipment (such as CO2 compressors, steam turbine generators, flash compressors, high pressure water-filling vapor pumps, and coal mills, etc.), and high technical requirements, so whether the installation, debugging and commissioning are carried out successfully will be directly related to the normal operation of the entire equipment in the future.

5. There are many types of pipes made of special materials.

The project involves low carbon steel, low alloy steel, heat resistant steel, austenitic stainless steel, nonferrous metal and nickel base alloy, etc. The welding process is complicated. Therefore, how to control the welding quality of the process pipeline to guarantee the safe operation of all process units is the key point of the quality control of the project.

6. High framework of gasification equipment and great logistics difficulty

The gasification equipment is not only complicated in process, but also has a large installation volume, and is as high as 98 meters. It is difficult for materials to be transported vertically and for operators to go up and down.

7. High electrical automation and great debugging difficulty

This project is of high automation degree. Under the premise of satisfying process detection and control functions, advanced and reliable instruments and materials are selected. Therefore, it is necessary to strengthen the control of each process in the installation of automatic control system, especially the debugging of the system.

8. The project occupies a large area, and the task is heavy on a tight schedule. There are lots of underground structures and more investments on environmental protection.

9. In the aspect of safety management, although the building height of pipe racks of this project gallery is low, about 15m at the highest point, there is a very big area of safety protection due to a total length of more than 15000 meters of pipe racks of the project, and the total weight of connecting beams of steel structure is up to more than 1500 tons.

10. Civil engineering is large in quantity but scattered in complex and diverse forms, partially with high architectural structure as well as broad distribution points, so it is the main link that affects the progress of the project as well as an important part of safety management. Construction in rainy seasons and nighttime detection lead to greater difficulty in environmental protection; the costs of green construction measures for safety civilization are increased accordingly, resulting in bigger difficulty in the control of safety cost of engineering construction.

From the above characteristics of the project, it can be seen that the implementation of project HSE management is a vital activity and process, and HSE management performance evaluation can be targeted to improve HSE management level. Therefore, it is necessary to construct scientific and targeted HSE management performance evaluation methods based on the above characteristics of the project.

5.2 Construction of HSE management performance evaluation indicators

AHP is a multi-objective and multi-criteria evaluation analysis method. Its advantage lies in the ability to quantify semi-structured or unstructured evaluation problems, so as to better transform qualitative indicators into quantitative indicators for further analysis (Zhang, Tian, & Feng, 2015). HSE management involves three main aspects of occupational health, safety and environment. It is often difficult to measure these three aspects through quantitative indicators, so is is necessary to convert qualitative indicators into quantitative indexes. Therefore, this study uses AHP to evaluate HSE management performance of the project.

The AHP evaluation method can basically follow the following procedures：

(1) Determining the indicators and levels of AHP, including three levels, i.e. target level, criterion level and indicator level；

(2) Determining the relative importance and score of each indicator by use of expert interview method, so as to carry out quantitative analysis；

(3) Using survey results to calculate indicator weight；

(4) Using the indicator weight and score to determine the performance value；

(5) Analyzing the evaluation results.

The establishment of appropriate HSE management performance is the basis for improving the HSE management system at the organization level. The HSE management of the project is established under the background of the enterprise's HSE management system. Therefore, the evaluation of the performance of the HSE management should consider the factors at the project level and the organization level synthetically. Based on the above AHP development process, the first choice should be the establishment of the evaluation indicator system of HSE management performance. Through expert interviews and reference to the existing literature, this study constructs an evaluation indicator system according to the core management contents of project HSE management, that is, in such three aspects as occupational health, safety and environment. Wang and Fu (2008) aimed at the study of occupational safety performance indicators. This study uses the ways of expert interviews and reference to the existing literature on HSE management performance evaluation. The evaluation system of HSE management performance constructed in this study is shown in Table 5-1.

Table 5-1 HSE management performance evaluation indicator

Target level	Criterion level	Indicator level
HSE management performance (A)	Occupational health management (B1)	Occupational health publicity C11
		Psychological consultation C12
		Medical service C13
		Healthcare facilities C14
		Pharmaceuticals and personal care products C15
	Safety management (B2)	Safety inspection at work C21
		Interprocess safety acceptance C22
		Machinery & equipment safety management C23
		Field fire protection management C24
		Protection product guarantee C25
		Safety accident handling C26
	Environmental management (B3)	Reasonable site planning C31
		Complete, tidy and clean living facilities C32
		Complete site marks & signs C33
		Closed worksite management C34
		Placing of materials in good order C35
		Timely pollutant disposal C36

As shown in Table 5-1, in the HSE management performance evaluation indicator system, the target level is the final result of HSE management evaluation - HSE management performance (A), which is a comprehensive indicator for measuring HSE management level. The criterion level contains three aspects of the HSE management system, namely occupational health (B1), safety (B2) and environment (B3), which are the core contents of HSE management. The indicator level futher breaks down the indicator level from the management goal of the criterion level. Among them, occupational health management is reflected in five aspects, namely occupational health publicity (C11), psychological counsultation (C12), medical service (C13), healthcare facilities (C14) and pharmaceuticals and personal care products (C15). Safety management is reflected in six indexes, namely safety inspection at work (C21), interprocess safety acceptance (C22), machinery & equipment safety management

(C23), site fire protection management (C24), protection product guarantee (C25) and safety accident handling (C26). Environmental management is also reflected in six indexes, i.e. reasonable site planning (C31), complete, tidy and clean-living facilities (C32), complete site marks & signs (C33) and closed worksite management (C34), placing of materials in good order (C35) and timely pollutant disposal (C36). The above indicators at the indicator level are composed of 17 items. In consideration of the key HSE management objectives of the construction site, the above evaluation indicators are constructed in such three aspects as occupational health, safety and environment, so as to comprehensively reflect the project HSE management level.

In the aforementioned HSE management performance evaluation indicator system, three elements of the criterion level, namely occupational health management H(B1), safety management S(B2) and environment management E(B3), are independent of each other. 17 evaluation indicators of the indicator level are not significantly correlated with each other, which satisfies the basic requirements of AHP.

5.3 HSE management performance analysis

5.3.1 Data source and processing

In this study, based on the Enteprise A, with eight large-scale construction projects contracted by it as the research object, HSE management performance of the eight projects is analyzed. The research data come from the questionnaire (appendix) and expert interview, mainly including the determination of the evaluation indicator system weight and SHE management evaluation indicator score, with the specific process shown as follows.

First of all, questionnaires of indicators with relative importance were distributed to 25 experts of the Enteprise A. Respondents should, on the basis of objective facts and experience, evaluate 3 evaluation indicators of the criterion level and 17 indicators of the indicator level by paired-comparisons method. A total of 21 questionnaires were collected in this round of questionnaires, of which 16 were similar in results. Then, these 16 people were invited to hold a meeting to deeply discuss the questionnaire results and to make a few corrections to form a consensus. Finally, the judgment matrixes of the criterion level and indicator level were determined. The 16 experts participating in the meeting discussion are shown in Table 4-1, and the judgment matrixes finally forming a consensus are shown in Table 5-2 and Table 5-3.

Table 5-2 Judgement matrix of criterion level indicators

Criterion levelindicators	Occupational health management	Safety management	Environmental management
Occupational health management	1	1/2	2
Safety management	2	1	3
Environmental management	1/2	1/3	1

In the aspect of management level scores of evaluation indicators, this study selects eight construction projects contracted by the Enterprise A for HSE management performance evaluation, and these projects are denoted by Projects A～H successively according to their start time, namely Project A, Project B, …… Project H. The score of HSE management level is collected at the project level, and the questionnaire items are measured by the five-point Likert scale. The scoring standard is: “Poor” with a score of 1, "Slightly poor" with a score of 2, "Average" with a score of 3, "Slightly good" with a score of 4, and "Very good" with a score of 5.

In this study, a total of 120 questionnaires were distributed to participants of the owner, supervisor and construction unit (Enterprise A) in each project and surrounding people around the project. Among them, 98 questionnaires were recovered for the Project A, and 92 valid questionnaires finally obtained after the elimination of 6 invalid ones with a similar score and same answers as well as uncompleted. 106 questionnaires were recovered for the Project B, and 96 valid questionnaires finally obtained after the elimination of 10 invalid ones; 111 questionnaires were recovered for the Project C, and 103 valid questionnaires finally obtained after the elimination of 8 invalid ones. Other projects were investigated in this way as well and not repeated one by one here. The mean of the valid questionnaires is the final score of the investigation index. After sorting-out and calculation, the score results are shown in Table 5-4.

Table 5-3 Judgment matrix of HSE evaluation index level indicators with relative importance

Evaluation indicators	Occupational health publicity	Psychological consultation	Medical service	Healthcare facilities	Pharmaceuticals and personal care products	Safety inspection at work	Interprocess safety acceptance	Machinery & equipment safety management	Field fire protection management	Protection product guarantee	Safety accident handling	Reasonable site planning	Complete, tidy and clean-living facilities	Complete site marks & signs	Closed worksite management	Placing of materials in good order	Timely pollutant disposal
Occupational health publicity	1	1/2	1	1/3	1												
Psychological consultation	2	1	3	1/2	2												
Medical service	1	1/3	1	1	3												
Healthcare facilities	3	2	1	1	2												
Pharmaceuticals and personal care products	1	1/2	1/3	1/2	1												
Safety inspection at work						1	1	1	1/2	1/2	2						
Interprocess safety acceptance						1	1	2	2	1/3	3						
Machinery & equipment safety management						1	1/2	1	1/2	1	3						

Field fire protection management	2	1/2	2	1	3	3						
Protection product guarantee	2	3	1	1/3	1	4						
Safety accident handling	1/2	1/3	1/3	1/3	1/4	1						
Reasonable site planning							1	1/3	1/5	1/2	1/3	1/5
Complete, tidy and clean-living facilities							3	1	3	1/2	1	1/2
Complete site marks & signs							5	1/3	1	1/2	1	1/2
Closed worksite management							2	2	2	1	1	1
Placing of materials in good order							3	1	1	1	1	1/3
Timely pollutant disposal							5	2	1/2	1	1/3	1

Table 5-4 HSE management performance evaluation indicator score of eight projects

Indicator category	Indicator name	A	B	C	D	E	F	G	H
Occupational health management (B1)	Occupational health publicity C11	3.61	2.66	2.76	4.54	2.64	3.56	4.5	4.11
	Psychological consultation C12	2.09	3.93	3.08	4.48	2.14	2.96	4.3	3.9
	Medical service C13	3.04	2.56	3.91	3.18	4.8	2.94	3.05	4.18
	Healthcare facilities C14	3.31	4.07	2.5	2.42	3.27	4.2	4.02	4.22
	Pharmaceuticals and personal care products C15	2.15	4.11	3.04	3.91	4.48	4.44	3.16	4.79
Safety management (B2)	Safety inspection at work C21	3.68	2.82	3.43	4.34	3.08	4.42	3.85	4.3
	Interprocess safety acceptance C22	2.03	4.29	4.04	3.26	2.62	4.11	3.21	3.77
	Machinery & equipment safety management C23	2.77	4.62	4.04	2.46	2.95	2.25	4.28	4.09
	Field fire protection management C24	2.83	2.23	4.7	2.98	3.54	3.1	3.71	4.31
	Protection product guarantee C25	2.69	4.17	2.42	2.31	2.92	4.59	3.83	4.23
	Safety accident handling C26	2.32	3.14	2.84	4.77	4.05	2.69	3.62	4.21
Environmental management (B3)	Reasonable site planning C31	4.58	4.45	3.4	2.25	3.45	2.99	4.15	4.28
	Complete, tidy and	3.56	2.88	2.23	4.43	3.23	3.31	3.1	4.54

clean-living facilities C32								
Complete site marks & signs C33	3.04	3.06	2.69	3.06	4.76	3.28	4.11	4.57
Closed worksite management C34	2.33	3.38	4.44	3.95	4.79	4.4	3.19	3.58
Placing of materials in good order C35	4.42	2.59	3.02	3.3	2.74	4.18	3.72	4.46
Timely pollutant disposal C36	4.37	2.78	4.28	4.52	4.2	4.04	4.09	3.65

5.3.2 Indicator weight analysis

5.3.2.1 Indicator weight analysis of criterion level

(1) Indicator weight of criterion level. As can be seen from the above, there are total three evaluation indicators at the criterion level - occupational health management (B1), safety management (B2), and environmental management (B3), and the calculation process of their weight is as follows.

1) Determination of the judgement matrix

After in-depth discussion with professionals and referring to the existing literature, the judgment matrix of criterion level indicators finally determined is shown in Table 5-2.

2) Weight calculation

The following formula can be obtained from Table 5-3:

$$\boldsymbol{W_1} = \sqrt[3]{\mathbf{1} * {}^{\mathbf{1}}/_{\mathbf{2}} * \mathbf{2}} = \mathbf{1.0000}$$

$$\boldsymbol{W_2} = \sqrt[3]{\mathbf{2} * \mathbf{1} * \mathbf{3}} = \mathbf{1.8171}$$

$$\boldsymbol{W_3} = \sqrt[3]{{}^{\mathbf{1}}/_{\mathbf{2}} * {}^{\mathbf{1}}/_{\mathbf{3}} * \mathbf{1}} = \mathbf{0.5503}$$

The following formula can be obtained after normalizing the judgement matrix:

$$W_E = 1 + 1.8171 + 0.5503 = 3.3674$$
$$W_1' = 1/3.3674 = 0.2970$$
$$W_2' = 1.8171/3.3674 = 0.5396$$
$$W_3' = 0.5503/3.3674 = 0.1634$$

Let

$$E' = \begin{vmatrix} 1 & 1/2 & 2 \\ 2 & 1 & 3 \\ 1/2 & 1/3 & 1 \end{vmatrix}$$

According to the above calculation results, the weight of the three indicators can be obtained as follows: $W^0 = (0.2970 \quad 0.5396 \quad 0.1634)^T$

3) Consistency check.

The incompatible judgment matrix is:

$$E'W^0 = \begin{vmatrix} 1 & {}^{1}/_{2} & 2 \\ 2 & 1 & 3 \\ 1/2 & {}^{1}/_{3} & 1 \end{vmatrix} \begin{vmatrix} 0.2970 \\ 0.5396 \\ 0.1634 \end{vmatrix} = \begin{vmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{vmatrix} \begin{vmatrix} 0.2970 \\ 0.5396 \\ 0.1634 \end{vmatrix} = \lambda W^0$$

Namely:

$$\begin{vmatrix} 1 * 0.2970 + {}^{1}/_{2} * 0.5396 + 2 * 0.1634 = 0.8936 \\ 2 * 0.2970 + 1 * 0.5396 + 3 * 0.1634 = 1.6238 \\ {}^{1}/_{2} * 0.2970 + {}^{1}/_{2} * 0.5396 + 1 * 0.1634 = 0.4918 \end{vmatrix} = \begin{vmatrix} 0.2970\lambda_1 \\ 0.5396\lambda_2 \\ 0.1634\lambda_3 \end{vmatrix}$$

The following can be obtained from the above formula:

$$\lambda_1 = {}^{0.8936}/_{0.2970} = 3.0088$$

$$\lambda_2 = {}^{1.6238}/_{0.5396} = 3.0093$$

$$\lambda_3 = {0.4918}/{0.1634} = 2.5692$$

$$\lambda_{max} = \lambda_3 = 3.0093$$

Table 5-5 Table of criterion level judgment matrix, relative importance and compatibility calculation

A	A_1	A_2	A_3	W_i	W_{ij}	λ_i	CI
A_1	1	1/2	2	1.0000	0.2970	3.0088	
A_2	2	1	3	1.1871	0.5396	3.0093	0.0047
A_3	1/2	1/3	1	0.5503	0.1634	2.5692	

$W_E = \sum_{i=1}^{M} W_i$ =2.7374 $W_i' = W_i / W_E$

The compatibility judgment formula is used to check whether the judgment matrix satisfies the consistency requirement. The relevant information is shown in Table 5-5. When n=3, RI is valued 0.58, then:

$$\text{CI} = \frac{\lambda_{max} - n}{n-1} = \frac{3.0093 - 3}{3-1} = 0.0047$$

$$\text{CI} = \frac{CI}{RI} = \frac{0.0047}{0.58} = 0.0081 < 0.10$$

It can be seen from CR<0.10 that the judgment matrix of the criterion level satisfies the consistency, and its relative importance vector satisfies the corresponding needs. Therefore, the weight of three indicators of the criterion level is:

$$W^0 = (0.2970 \;\; 0.5396 \;\; 0.1634)$$

5.3.2.2 Indicator level weight analysis

After in-depth discussion by the expert group and referring to the existing literature, the judgement matrix at the indicator level finally determined is shown in Table 5-3. Through calculation, the product of the indicator weights at the criterion level and at the indicator level is the comprehensive weight at the indictor level. The calculation results are shown in Table 5-6:

Table 5-6 Comprehensive weight of indicator level

Target level	Criterion level	Criterion level weight	Indicator level	Indicator level weight	Comprehensive weight of indicator level
HSE management performance (A)	Occupational health management (B1)	0.297	Occupational health publicity C11	0.1303	0.0387
			Psychological consultation C12	0.2669	0.0793
			Medical service C13	0.1202	0.0357
			Healthcare facilities C14	0.3066	0.091
			Pharmaceuticals and personal care products C15	0.1761	0.0523
	Safety management (B2)	0.5396	Safety inspection at work C21	0.1361	0.0734
			Interprocess safety acceptance C22	0.1925	0.1039
			Machinery & equipment safety management C23	0.1456	0.0786
			Field fire protection management C24	0.2473	0.1335
			Protection product guarantee C25	0.2161	0.1166
			Safety accident handling C26	0.0624	0.0337
	Environmental management (B3)	0.1634	Reasonable site planning C31	0.0534	0.0087
			Complete, tidy and clean-living facilities C32	0.1693	0.0277

	Complete site marks & signs C33	0.1278	0.0209
	Closed worksite management C34	0.2091	0.0342
	Placing of materials in good order C35	0.1479	0.0242
	Timely pollutant disposal C36	0.2926	0.0478

5.4 Result analysis

Through the indicator level weight and evaluation indicator score of HSE management performance, the comprehensive scores and ranking of occupational health management, safety management and environmental management of the Project A are obtained, as shown in Table 5-7.

Table 5-7 Score of the criterion level and index level of the Project A

Criterion level				Indicator level			
Indicator name	Weight	Score	Weighted score	Name	Weight	Score	Weighted score
Occupational health management (B1)	0.297	2.79	0.470383	Occupational health publicity C11	0.1303	3.61	0.47
			0.557821	Psychological consultation C12	0.2669	2.09	0.56
			0.365408	Medical service C13	0.1202	3.04	0.37
			1.014846	Healthcare facilities C14	0.3066	3.31	1.01
			0.378615	Pharmaceuticals and personal care products C15	0.1761	2.15	0.38
Safety management (B2)	0.5396	2.72	0.500848	Safety inspection at work C21	0.1361	3.68	0.50
			0.390775	Interprocess safety	0.1925	2.03	0.39

				acceptance C22			
			0.403312	Machinery & equipment safety management C23	0.1456	2.77	0.40
			0.699859	Field fire protection management C24	0.2473	2.83	0.70
			0.581309	Protection product guarantee C25	0.2161	2.69	0.58
			0.144768	Safety accident handling C26	0.0624	2.32	0.14
Environ mental management (B3)	0.1634	3.66	0.244572	Reasonable site planning C31	0.0534	4.58	0.24
			0.602708	Complete, tidy and clean living facilities C32	0.1693	3.56	0.60
			0.388512	Complete site marks & signs C33	0.1278	3.04	0.39
			0.487203	Closed worksite management C34	0.2091	2.33	0.49
			0.653718	Placing of materials in good order C35	0.1479	4.42	0.65
			1.278662	Timely pollutant disposal C36	0.2926	4.37	1.28

The calculation process of the Project B ~ Project H are similar and not repeated here. According to the calculation, the score and ranking of the criterion level of each project are shown in Table 5-8.

Table 5-8 shows that the occupational health management score of eight projects is between 2.79 and 4.22, with the mean value of 3.51; the score of safety management is between 2.72 and 4.15, with the mean value of 3.46; the score of environmental management is between 3.02 and 4.06, with the mean value of 3.71. On the whole, there is obvious difference in the comprehensive score of H, S and E management of eight projects, namely, the HSE management level of eight projects is not equivalent. The HSE composite score of the Project H is the highest among the eight projects, so the HSE management level of the Project H can be seen as the best among the eight projects. The composite scores of occupational health and safety management of the Project A are the lowest among the eight projects, and the composite score of its environmental management also ranks low, indicating that the HSE management level of the Project D still cannot meet the requirements and its HSE management needs to be strengthened most.

Table 5-8 Score and ranking of the criterion level

Indicator	A	B	C	D	E	F	G	H
Occupational health management	2.79	3.67	2.95	3.6	3.28	3.68	3.89	4.22
Ranking of occupational health management	8	3	7	5	6	4	2	1
Safety management	2.72	3.53	3.7	3.11	3.11	3.65	3.74	4.15
Ranking of safety management	8	5	3	6	6	4	2	1
Environmental management	3.66	3.02	3.53	3.9	3.98	3.86	3.69	4.06
Ranking of environmental management	6	8	7	3	2	4	5	1

According to the comprehensive weight of criterion level indicators shown in Table 5-7 and the composite score of criterion level indicators shown in Table 5-4, the HSE management performance of the Project A can be obtained as shown in Table 5-9.

Table 5-9 HSE management performance and ranking of the eight projects

Project	A	B	C	D	E	F	G	H
HSE management performance	2.89	3.49	3.45	3.38	3.3	3.69	3.77	4.15
Ranking	8	6	7	4	5	3	2	1

As shown in Table 5-9, the HSE management performance of the eight projects is between

2.8 and 4.2, ranking H>G>F>D>E>B>C>A. Among them, the Project H ranks the highest at 4.15; the Project A ranks the lowest at 2.89; the highest value is 1.44 times the lowest value. As can be seen from the table, there is a distinct gap in the HSE management performance of the eight projects, which indicates that the HSE management level of the eight projects is quite different, and the HSE management and control ability needs to be further improved.

From Project E, HSE management performance shows a trend of gradual improvement, and the trend of improvement is obvious. Because the projects A-H are sorted in the order of time, and the enterprise begins to implement the two-level HSE management system in the D period of the project, the results show that the HSE management performance of the project is improving gradually, further reflecting that the HSE management measures formulated by the enterprise can achieve good results.

5.5 Recommendations for improving HSE management

In view of the above evaluation results of HSE management performance, this study further explores the problems that need to be improved, and proposes pertinent improvement measures for these problems, which are mainly shown as follows.

5.5.1 Recommendations for occupational health management

In the aspect of the prevention food poisoning of employees, the food purchasing personnel of the enterprise must well check the quality of raw food material. The time from the processing to the supply of self-processed food should not exceed 2 hours. The food left from the last meal must be stored in the refrigerator and reheated before serving. Disinfection management of food processing equipment, containers and tableware should be strengthened. Any employee who suffers from such gastrointestinal diseases as vomiting, abdominal pain and diarrhea as well as other diseases like sore throat and exudative & suppurative skin diseases should be given rest and receive medical treatment.

In the aspect of the prevention of toxic gas poisoning, during pile digging, once the hole is more than 6m deep, first a blower should be used to blow the hole for ventilation, so as to remove any harmful gas from the hole; then small animals or other open flames should be used to check the pit bottom for harmful gases such as biogas; operators can enter the hole for working only after normal reaction. The construction process adopts the way of air supply to the hole from the ground, so as to ensure that the working plane is well ventilated.

In the aspect of the prevention of heatstroke, rendan mini-pills and Huoxiangzhengqi Solution must be prepared at the construction site. The construction operation must avoid the noon scorching sun time. Adequate supply of boiled water must be ensured, and construction staff are required to drink more water, and take more rest. In hot weather, cold water can be used to wash the head and neck to help dissipate heat. In case of heatstroke, the patient should be moved to the shade, water should be added to the patient, and a wet towel should be used to lower the temperature of the patient in the way of cold compress.

In the aspect of the prevention and curing of occupational diseases, the enterprise should organize the occupational health examination among the workers before and during their work and when they leave the company, and inform the workers truthfully of the examination results. Workers should have the right to know the occupational disease hazards and consequences and protective measures to be taken in the workplace. The Project Department should provide workers with occupational health training before they take up their posts and regular occupational health training while they are on duty, popularize occupational health knowledge, and urge workers to abide by the laws, regulations, statutes and operational rules for the prevention and treatment of occupational diseases, and guide workers to use occupational disease protection equipment and personal occupational disease protection equipment.

In the aspect of noise protection, when employees are affected by noise, hearing protectors should be used when the standard is exceeded. The criteria are as follows:

(1) In case of 8 hours of continuous work per day, the sound level standard should be 85 decibels and the temporary allowable sound level should be 90 decibels;

(2) In case of 4 hours of continuous work per day, the sound level standard should be 88 decibels and the temporary allowable sound level should be 93 decibels;

(3) In case of 2 hours of continuous work per day, the sound level standard should be 91decibels and the temporary allowable sound level should be 96 decibels;

(4) In case of 1 hour of continuous work per day, the sound level standard should be 94 decibels and the temporary allowable sound level should be 99 decibels;

The Project Management Department should abide by relevant laws and regulations, and urge workers to properly use and wear protective equipment. For example, when workers are exposed to flying particles, molten metal, liquid chemicals, chemical gas, steam or potentially harmful light radiation or heat, their eyes and faces should be effectively protected. Where workers' feet may be damaged by falling or rolling objects, or objects likely to puncture the sole, or may be in danger of electric shock, workers should wear protective shoes such as safety shoes and insulant shoes, etc. Moreover, workers must wear appropriate protective gloves when they are exposed to toxic substances, severe cuts or scratches, severe bruises, stab wounds and so forth.

5.5.2 Recommendations for safety management

Safety accidents are the result of coupling between human and physical factors, and cutting off their coupling path in time or space is an effective way to prevent the safety accidents of construction projects (Yan, He, & Huang, 2013). Based on this, the following suggestions for improving safety management are proposed.

Confined space means that through strict examination and approval, the operator may enter to carry out the work of construction, maintenance or other arrangement. The confined space stipulated by the enterprise generally involves pile & deep pit digging, hot-line work and work at heights. The HSE Management Department and Project Department must determine all confined spaces according to the situation of the project. On the basis of the results of assessment, the Project Department should compile the Safe Operation Scheme and put forward control requirements, inform employees of the dangerousness of all confined spaces to, and identify them when necessary. The Safe Operation Scheme should be submitted to the Safety Management Department for review and undergo on-site inspection before suggestions for revision are proposed, and then reported to Chief Engineer for approval before implementation. The Project Department should responsible for training relevant operators in industrial hygiene, safe operation procedures, and gas defense & first aid emergency knowledge, etc.

For the specific operation requirements of confined space, operators can refer to the Safe Operation Scheme and relevant national laws and regulations. For example, in terms of electrical operation control, electricians must be trained by a qualified department, and hold the qualification certificate. The Project Department is responsible for the registration of on-site electricians in the "Registration Form of Post Holders" and defining the list of qualified electricians. The Project Department should provide electrical operators with suitable personal protective equipment, such as grounding cables, insulated rubber hoses, rubber gloves, rubber covers, insulating rubber and sleeves, etc. All electric switchboards should be closed and locked, all wires and cables should be in good condition, and any device with an extension cord can only be used temporarily. All electrical switches, including circuit breakers, must indicate the items under their control.

Safety belts, safety nets and safety helmets should be used for work at heights. All kinds of parts should not be removed at will, and damaged parts should not be used. The seatbelt must be fastened according to the requirements, and should be fastened to vertical structures without sharp and acute edges, should not be used for high-altitude purposes while hung at low places, and should not be replaced by a rope. The helmet must be worn correctly when used. Do not use unlocked hooks when using a personal fall protection system. The hole cover plate should be stiff enough to support the human body and equipment weight. The protective measures of "four holes and five edges" should conform to the relevant regulations. Personal fall protective devices should not be used for towing, binding or lifting objects. Tools, parts, materials, etc. used for high-altitude work must be packed in tool bags. Materials, tools, or other objects must not be dropped from a height. After the work is completed, tools, odd materials, parts and other easy-to-fall objects should be cleaned up in time, to prevent them from falling and injuring people.

If there is a risk of falling in a dangerous equipment or operating area, such as mobile equipment, jagged or sharp objects, scaffolding, etc., appropriate anti-fall devices and warning signs should be added. The operator should check the anti-fall devices before each use and stop using any damaged device immediately. The high-altitude operator needs to wear suitable shoes for work. When engaging in production activities by standing on the ladder, they should try to make their body in the middle of the ladder. Except for the herringbone ladder, the highest standing position of the operator on the ladder should be below the two highest steps, and the number of people standing on the ladder at the same time should not exceed one.

The risk assessment method should be established on the site of the project, and the "LEC method" can be adopted, namely $D=L\times E\times C$：

L - The probability of accident occurrence；

E - The frequency of human exposure to risk factors;

C - The loss caused by an accident;

D - Value at risk.

The larger the D, the greater the risk; at D≥150, the risk is considered as an unacceptable risk. Each parameter can be determined by the following way.

(1) The value of L can be determined by the following factors:

When the score reaches 10 points, the possibility of accident occurrence is characterized as "completely predictable", and when the score reaches 6 points, the possibility of accident occurrence is characterized as "very likely". When the score reaches 3 points, the possibility of accident is characterized as "possible but not often", and when the score reaches 1 point, the possibility of accident occurs is "small, completely unexpected". When the score reaches 0.5 points, the possibility of accident occurrence is characterized as "very unlikely", and when the score reaches 0.2 points, the possibility of accident occurrence is characterized as "extremely unlikely". When the score reaches 0.1 point, the possibility of accident occurrence is characterized as "actually impossible ".

(2) The value of E can be determined by the following factors:

When the score reaches 10 points, the frequency of human exposure to dangerous environment is characterized as "continuous exposure", and when the score reaches 6 points, the frequency of human body exposure to dangerous environment is characterized as "exposure in daily working hours". When the score reaches 3 points, the frequency of human body exposure to dangerous environment is characterized as "once a week", and when the score reaches 2 points, the frequency of human body exposure to dangerous environment is characterized as "once a month". When the score reaches 1 point, the frequency of human exposure to dangerous environment is characterized as "once or several times a year". When the score reaches 0.5 points, the frequency of human exposure to dangerous environment is characterized as “very rare”.

(3) The value of C can be determined by the following factors:

When the score reaches 100 points, the result of loss caused by accident is characterized as "catastrophe, many deaths", and when the score reaches 40 points, the result of loss caused by accident is characterized as "disaster, several deaths". When the score reaches 15 points, the result of loss caused by accident is characterized as "very serious, one death", and when the score reaches 7 points, the result of loss caused by accident is characterized as "serious, severe injury". When the score reaches 3 points, the result of the loss caused by the accident is characterized as "significant, crippling", and when the score reaches 1 point, the frequency of human body exposure to dangerous environment is characterized as "eye-catching, requiring rescue".

(4) The value of D can be determined by the following numerical values:

When the score exceeds 320 points, the hazard level is characterized as "extremely dangerous and unable to continue working"; when the score exceeds 160 but does not exceed 320 points, the hazard level is characterized as "highly dangerous and in need of immediate improvement"; When the score exceeds 70 but does not exceed 160 points, the hazard level is characterized as "significantly dangerous, requiring improvement", and when the score exceeds 20 but does not exceed 70 points, the hazard level is characterized as "generally dangerous, requiring attention". When the score does not exceed 20 points, the hazard level is characterized as "slightly dangerous, acceptable".

The HSE Management Department, HSE management team and Project Management Department should grade the identified hazards according to the above table values. The significant risks, high risks, and extremely dangerous risks that are assessed as unacceptable risks should be controlled and summarized into the "List of unacceptable risks", and safeguard measures be developed.

5.5.3 Recommendations for environmental management

As learned from the questionnaires, eight projects have serious problems in wastewater discharge management. Most of the sources of construction wastewater is the wastewater discharged during the construction of the project as well as car-washing and canteen wastewater. Domestic sewage and construction wastewater should, after precipitation, be discharged into the centralized sewage treatment center via the urban sewage pipe network, and discharge standards should meet the discharge standards divided by functional zones in office and construction areas.

In addition, construction projects can also cause waste gas, noise, solid waste and other pollution. Therefore, the construction unit should abide by the regulations for the prevention and control of noise pollution issued by the local administrative department of environmental protection and health & epidemic prevention department, preferentially adopt advanced construction technology with low noise pollution, strengthen the maintenance of mechanical equipment, reduce any adverse effect on the living and working environment of surrounding residents, and at the same time ensure that solid wastes can be recycled.

The project management team should abide by the relevant environmental protection laws and regulations, rationally select and utilize raw materials & energy, use green building materials and clean construction technology with high material utilization efficiency and less pollutant emission, strengthen management and reduce pollutants. In the construction site layout, the Project Department should reasonably arrange the flow direction of sewage, and set up the silt basin beside the mixer. Before wastewater treatment and emission, the sedimentation tank must be cleaned, with moderate sewage flow maintained to facilitate the precipitation of mud and sand. Moreover, the environment manager should carry out PH test of discharged wastewater from time to time, fill in the "Monitoring Record of Sewage Discharge from the Construction Site". Wastewater from various sources must be discharged into the urban sewage network as much as possible, putting an end to unorganized wastewater discharge. The HSE management team should, on a quarterly basis, carry out casual inspection of wastewater discharge from various subproject divisions of the company or Project Management Department, and record on the "Record of Daily Operation Check", so as to further supervise and urge its rectification.

To effectively control exhaust emission, prior to the leveling of ground and commencement of earthwork, construction fences, hardened entrances & exits, vehicle washing facilities, drainage facilities and silt basins, etc. must be built. As much flying dust as possible should be controlled during construction, and it should be ensured that the mixer has been filled with mixing water before concrete mixing on the site. Direct dumping of construction waste from the building is not allowed, and construction waste must be containerized for vertical transport to the ground. It should be guaranteed that construction waste transfer is not overloaded and is provided with sprinkling and fly-away prevention measures; the garbage truck must be covered and enclosed.

In order to reduce noise pollution, the Project Management Department should strengthen the maintenance of mechanical equipment, and ensure that the mechanical equipment used at the site may not be operated with malfunctions, and no such noise pollution as abnormal noise will occur. For the equipment the noise of which cannot be reduced in some cases, a good hearing protection program should be established. If the noise exceeds the standard, the staff should wear earplugs and other personal protective equipment. The HSE management department should, at least once a month, monitor the noise level around construction walls of construction in process, carry out instantaneous monitoring of the noise at operating points, and fill in the "record form of noise monitoring at the construction site". If the monitoring value is found to exceed the limit set by the environmental protection department and the health department, the project department should be urged to take corrective measures in a timely manner. In the case of night construction required due to the time limit for a project or the construction technology, construction personnel must apply to the relevant administrative department for the night construction permit before carrying out night construction, publicize the relevant permit, and do a good job in its explanation in due time.

As for the treatment of solid waste, the principle of waste reuse should be adhered to and the waste should be used as far as possible. For example, the reverse side of waste copy paper can be used as scratch paper for documents. Non-reusable paper, waste glass, scrap metal, waste packaging and so on should be recovered by the office or the project department as a whole, and the Waste Disposal Statistics Form should be filled in for recording, and then the waste should be sold to the waste recycling station for comprehensive use. The waste that cannot be reused and recycled should be centralized and sent to the garbage station for unified treatment. Hazardous waste recycling bins should be set up to collect used batteries, waste ink cartridges, waste fluorescent lamp tubes, waste paint containers, etc. The office is responsible for contacting the units with relevant handling capacity and qualifications to handle the recovered hazardous wastes. The materials scattered in the course of transportation should be cleared by the transporter. The construction site should be surrounded by protective panels to prevent the spread of waste. The waste generated by mechanical repairs should be placed by the repairman as a whole. Items that can be recycled should be delivered to project or material supply department, and should be recorded by the department and sold to waste recycling station. Unusable objects should be treated in a centralized and classified manner. When a contract is signed with the subcontractor, influence should be exerted on the supplier in accordance with the provisions of the Procurement and Subcontract Control Procedures, and the supplier should be supervised to centralize the storage of construction waste, and prevent the spread of the waste. HSE management team and project department should inspect the construction site on a regular basis, and the results should be recorded in the “Daily Operation Check Record Form”.

In order to save energy, when using air conditioning in office area, we should check whether the doors and windows are closed or not, to prevent the increase of air conditioning energy consumption. Lights should be shut off in time when no one is working, and electric equipment should be shut off when no one uses it. We advocate saving electricity, control indoor air-conditioning temperature, promote water conservation, strengthen the inspection of pipe fittings, strictly prohibit water valve running, oozing, leaking and dripping, and strengthen the daily inspection of construction machinery to ensure the normal use of electricity and oil. We should reduce paper consumption, promote paperless office, improve the ratio of paper double-sided utilization, set up the consciousness of recycling and reuse of resources among the whole project staff, and continuously improve the reuse rate of resources.

Environmental factors can be evaluated by reference to the following evaluation standards:

(1) The likelihood of occurrence m1

The score is 5 when the likelihood of occurrence is "has occurred (often occurs, not less than once a day)", and the score is 4 when the likelihood of occurrence is "high probability of occurrence (or has ever occurred)"; When the likelihood of occurrence is "low probability of occurrence (or occasional occurrence)", the score is 3, and when the likelihood of occurrence is "will possibly occur (has not yet occurred)", the score is 2. The score is 1 when the likelihood of occurrence is "will never occur at all."

(2) The likelihood of detection/prevention m2

When the likelihood of detection / prevention is "hard to detect / prevent", the score is 3, and when the likelihood of occurrence is "detectable / preventable, there is no measure", the score is 2. The score is 1 when the likelihood of occurrence is "there are regular precautions".

(3) The impact degree m3

When the impact degree is "serious (even involving other companies)", the score is 5; when the impact degree is "big (the company can treat it internally or the pollutant emission is large)", the score is 4; when the impact degree is " average (the unit can treat it or the pollutant discharge is small)", the score is 3; when the impact degree is " small (the operator can treat it)", the score is 2; when the degree of impact is “no influence at all”, the score is 1.

(4) Accidents/complaints m4

When the accident or complaint situation is "the environmental pollution accident has occured but no measures have been taken", the score is 5, when the accident or complaint situation is "the environmental pollution accident has occured and measures have been taken ", the score is 4 points; When the accident or complaint situation is a "complaint outside the company", the score is 3; when the accident or complaint situation is a "complaint within the company", the score is 2; and when the accident or complaint situation is "no accident has occurred, or a complaint has occurred and has been resolved", the score is 1.

5.5.4 Recommendations for HSE management & supervision

The HSE management department is responsible for the daily supervision of the operation of the HSE management systems in various departments. The supervision methods are as follows:

(1) The HSE management department should establish the HSE management information system to monitor the HSE management throughout the whole process, publicize the reporting methods for insufficient HSE management on the field billboard, and welcome the project members and the public to supervise the HSE management of projects.

(2) Monitoring of the health and safety environment. Each project department can determine its own monitoring content, such as noise, solid waste treatment and its comprehensive utilization, cleaning and sanitation, water and electricity resource consumption, etc. The HSE management department should conduct quarterly inspection, verifying the on-site implementation of the HSE management system, and clearly recording the status of inspection on the "daily operation inspection record". At least once a week, the project department should check the wastewater discharge at the construction site and fill in the "sewage discharge record form of the construction site". The HSE management department and project manager should irregularly develop the objectives, indicators and management plans according to the specific project, check the environmental performance and occupational health & safety performance of construction in process, and fill in the "daily operation inspection record". With regard to the items that enterprises cannot monitor independently, such as air

quality and wastewater, they should be timely monitored by the relevant environmental monitoring department contacted by the HSE management department, and the monitoring report should be archived in the HSE management department.

(3) Monitoring of the operational process. The HSE management department should, on a yearly basis, organize an HSE management work meeting, reporting the completion of the work of each department, and bringing forward rectification measures and next objectives. The contents of inspection include the completion of objectives and indicators, training, emergency preparedness, environmental protection operation, information exchange, and implementation of corrective measures for nonconformities. Daily monitoring required by the higher authorities and relevant government departments should be carried out in active coordination with them.

(4) Each project management department should take measures to control the consumption of water, electricity and gas at the construction site, and improve the utilization efficiency of water, electricity and gas. Each project management department should carefully record the HSE inspection and ensure the data is authentic. Project management department members should cooperate with the HSE management department in quarterly inspection, including the implementation of HSE management requirements at the inspection site, and the adoption of preventive and corrective actions for any phenomenon detected that fails to meet the administrative provisions.

5.5.5 Emergency preparation and response recommendations

Major HSE accidents that may occur in the project include high-pressure gas cylinder explosions, blasting supplies explosions, accidental oil leaks, fires, landslides, electric shock injuries, toxic gas poisoning, food poisoning, high-altitude falls and major mechanical injuries. The enterprise should set up an emergency handling organization to perform its specific duties before and after the occurrence of an emergency, so as to maintain the coordination and consistency of the entire team, To minimize the possible accident consequences, the HSE management department should adjust the emergency management organization according to the personnel changes at the beginning of each year to ensure the implementation of the emergency organization. The emergency management institution is permanently under the HSE management department.

In the aspect of emergency response, emergency response should be rapid. In the event of explosion, the detector should promptly transmit this information to the project manager, HSE management department, management representative and general manager should take measures to control the expansion of the accident without personal danger.

Firefighting facilities and accesses should not be obstructed at any time in case of fire. Firefighting facilities should not be used for other purposes. In case of any damage to emergency lights and portable fire extinguishers, the logistic support department should organize the maintenance. Those who intentionally damage the firefighting facilities will be severely punished. No smoking, combustion and other high-temperature operations are approved by the HSE Management Group. The improvement of construction technology and facilities which may bring fire risks should be first planned in the technical measures of environmental safety and approved by the HSE management department of the enterprise. The logistics department is responsible for regular organization of fire equipment inspection and maintenance.

In case of chemical or oil leakage, the detector should immediately take measures to stop the leakage, report to the HSE management team at the first time, and take all measures to cut off the source of the accident. For chemicals and oils that have been leaked on the ground, the detector should apply tissues or rags to clean up the leaking chemicals if there is a small amount of leakage. If the leakage is large, the detector should use dry sand or absorbent cotton immediately to surround the leaked chemicals and oil products to prevent their further spread, and then use absorbent cotton, paper towels or rags to clean up the leaking chemicals and oils. All resulting wastes should be treated as hazardous wastes.

For heavy worker casualties, the emergency team should immediately bandage the injured staff and take care of the scene. The safety worker should dial 120 or the emergency telephone numbers of other external medical institutions to request rescue, or escort the injured to nearby hospitals immediately, depending on the degree of injury. All major industrial accidents should be reported to HSE Department, Project Manager and General Manager as soon as possible. HR department should contact social security institutions in time and report the accident. The safety management department should organize the project department to deal with the accident.

5.6 Summary of this chapter

According to the distinguished characteristics of construction projects, this chapter first sets up the evaluation indicators of HSE management performance in the three aspects of HSE management, namely H, S and E; secondly evaluates the HSE management performance of eight projects by use of the above evaluation indicators and AHP method, with the results showing that there is an obvious gap in HSE management performance among eight projects, and there is a gradually increasing trend along with the time sequence of projects. The results indicate that the HSE management improvement method proposed by the Enterprise A has obtained good results and attained the aim of improving HSE management performance of projects. Finally, it gives suggestions for improving HSE management performance in order to provide an effective method for further improving HSE management performance.

Chapter 6: Comprehensive Efficiency Evaluation of Construction Projects

The preceding part discusses the evaluation of HSE management performance, and HSE management performance is the key component of project efficiency, so it is necessary to further discuss and consider the comprehensive project efficiency evaluation of HSE management performance on the basis of the previous chapter. In this chapter, firstly the evaluation indicators of project efficiency are constructed. Secondly, the key influencing factors of evaluation indicators are analyzed in depth to fully measure the value of evaluation indicators. Finally, with the eight projects selected in the preceding chapter as the case study object, the evaluation indicators constructed are taken into consideration, the efficiency of the eight projects analyzed by using the DEA method, and suggestions for improving project efficiency further put forward.

6.1 Construction of evaluation indicators

According to the DEA method the input and output are considered comprehensively. The efficiency is evaluated in terms of the input and output ratio, and it can be seen that evaluation indicators include the input indicator and output indicator. Among them, the input indicator represents the input quantity of project resources and belongs to cost indicators. The output indicator indicates the output quantity of the project after resource input and belongs to efficiency indicators. In the case of more efficiency output under less input resources of the project, the project can be considered as most efficient.

At present, the construction industry is still in a labor- and capital-intensive phase. The construction process of construction projects often requires the input of a lot of human resources, and the human input of projects should serve as the input indicator. Moreover, contractors need to spend lots of costs on the completion of the building process of construction projects. Their cost inputs are directly related to the enterprise profits, and therefore are one of the important determinants of enterprise development and should also serve as input indicators.

Therefore, the input indicators constructed in this study are divided into labor and cost indicators.

SPI, CPI and quality performance are traditional project evaluation indicators, commonly known as the "Iron Triangle" of project management. These three indicators measure the progress, cost objective and realization of quality objectives of the project. Based on this, Zahedi-Seresht et al. (2014) used SPI, CPI and quality performance as output indicators of project efficiency evaluation. By reference to the literature, and combined with the key management objectives of large-scale construction projects, this study argues that SPI, CPI and quality performance should be used as output indicators of efficiency evaluation. Liao and Song (2016) proposed the evaluation method for the safety efficiency of construction projects, and at the same time the Chinese strategy of building an eco-friendly country and the concept of sustainable development in the construction industry require large-scale project contracting enterprises to pay attention to HSE management. HSE management is related to the sustainable development prospect of enterprises and society, and is a new and important management objective of construction projects required for the sustainable development of enterprises and society, so this study argues that HSE management performance is an important evaluation indicator of project efficiency.

To sum up, this study establishes a comprehensive evaluation indicator system for construction project efficiency, as shown in Figure 6-1, and the definitions of each comprehensive evaluation indicator are shown in Table 6-1. Input indicators are labor and cost, and output indicators are SPI, CPI, quality performance and HSE management performance. Output indicators comprehensively consider the traditional indicators and the new evaluation indicators that fit the development requirements of the current engineering construction industry. The above indicators can fully reflect the efficiency of construction projects.

6.2 Analysis of influencing factors of evaluation indicators

For construction projects, human input can be roughly divided into three categories: managerial personnel, technical personnel and ordinary workers. The construction process of current construction projects is often very complicated and usually needs the adoption of professional construction technology, and at this time the corresponding professional technicians are required. In addition to professional technicians, those unprofessional jobs are implemented mainly by ordinary workers. Moreover, ordinary workers often serve to collaborate with professional technicians to complete professional technical work together.

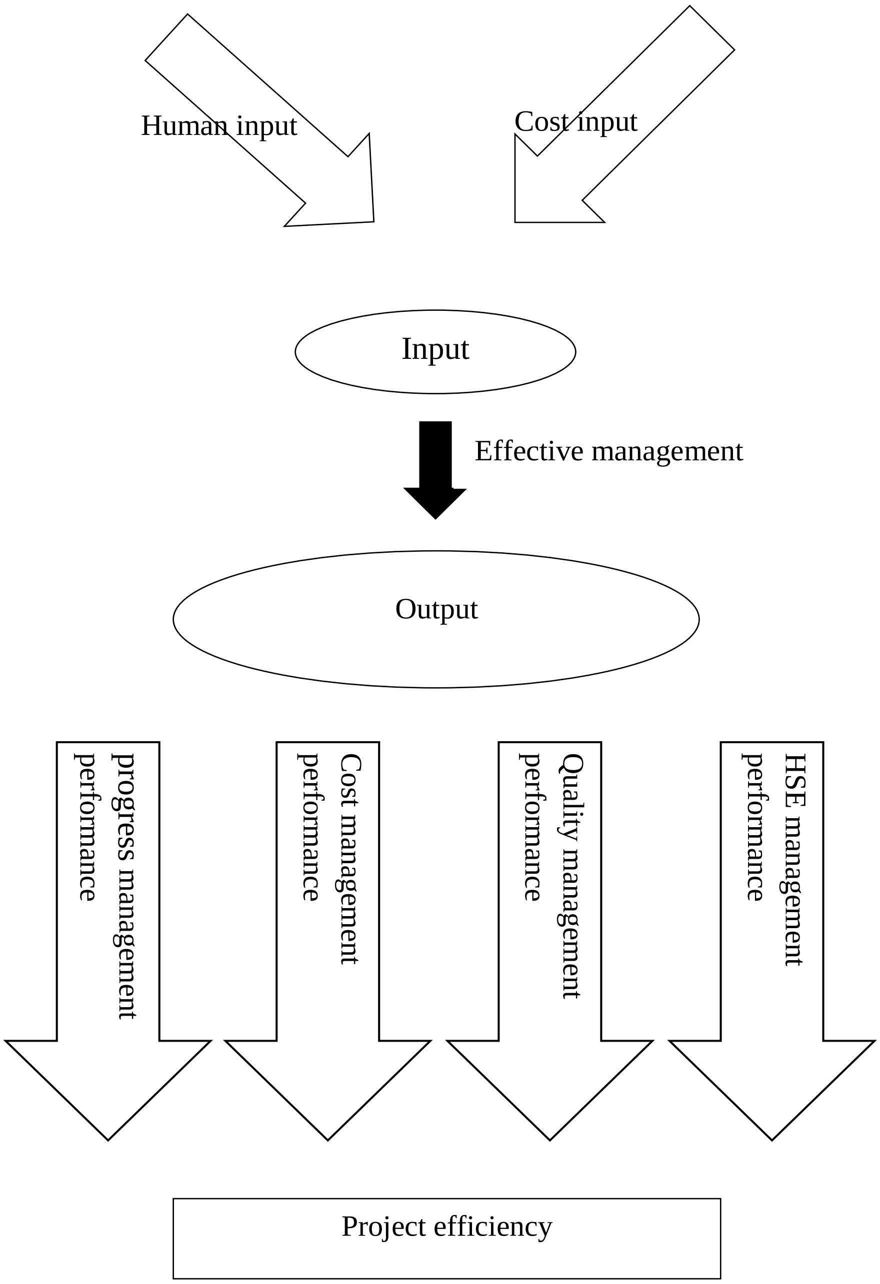

Figure 6-1 Evaluation indicators of construction project efficiency

In terms of cost input, the most important input resources of construction projects are manpower, materials & equipment and engineering machinery. Therefore, cost input can be divided into labor cost, material cost and mechanical cost. Besides them, the cost is classified as other cost in this study.

Table 6-1 Definitions of comprehensive evaluation indicators of construction project efficiency

Type	Name	Definition
Input indicators	Human input	The numerical magnitude represents the volume of human input
	Cost input	The numerical magnitude represents the volume of cost input
Output indicators	SPI	The numerical value represents the realization of the project progress goal: SPI>1， representing the actual progress ahead of the planned progress; SPI=1，representing the actual progress consistent with the planned progress; SPI<1，representing the actual progress behind the planned progress.
	CPI	The numerical value represents the realization of the project cost target: CPI>1， representing the actual cost lower than the planned cost; CPI=1， representing the actual cost equal to the planned cost; CPI<1，representing the actual cost higher than the planned cost.
	Quality performance	[0，1]，The numerical magnitude represents the realization of quality objectives
	HSE management performance	[0，5]，The numerical magnitude represents the realization of HSE objectives

As the Earned Value (EV) progress evaluation index, SPI converts time parameters into investment parameters for analyzing the gap between the planned progress and actual progress in the process of project implementation, and numerically SPI = EV/PV (PV is the planned investment of the project to be completed). When the construction project has been completed, SPI can be expressed as the ratio between the planned construction period and the actual construction period. CPI is the cost analysis indicator of Earned Value, which is equal to the ratio of the planned cost to the actual cost.

The quality performance is used to measure the quality management level of the project. As the Enterprise A is a large-scale state-owned construction project contracting enterprise, in order to improve the market competitiveness of the enterprise, its quality management regulations require that its key projects should be of good quality, so as to enhance the market competitiveness and reputation of the enterprise. The good rate of work package is the key assessment indicator of project quality management level, so this study utilizes the good rate of work package to reflect the quality performance.

In summary, this study puts forward the comprehensive evaluation indicators and key influencing factors of construction project efficiency, as shown in Figure 6-2, with the detailed definitions as shown in Table 6-2.

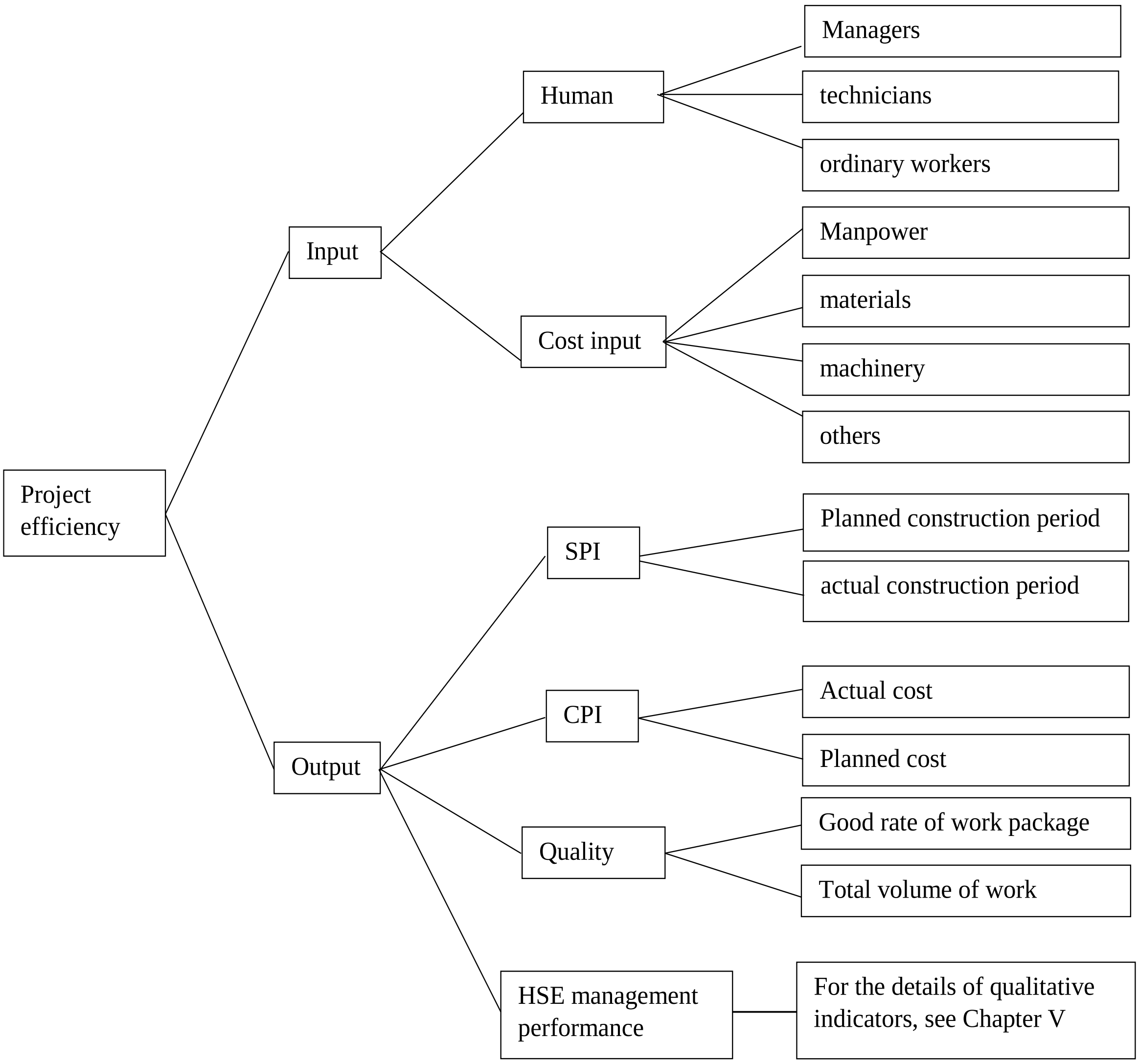

Figure 6-2 Diagram of evaluation indicators and influencing factors of construction project efficiency

Table 6-2 Definitions of evaluation indicators of construction project efficiency

Type	Name	Definition
Input	Human input	Managers + technicians + ordinary workers
	Cost input	Manpower+ materials+ machinery +others
Output	SPI	Planned construction period/ actual construction period
	CPI	Planned cost/Actural cost
	Quality performance	Good rate of work package/total volume of work package
	HSE management performance	For the details of qualitative indicators, see Chapter V

6.3 Case study

6.3.1 Data sources

In this study, based on the Enterprise A, with eight large-scale construction projects contracted by it as the analysis object, the process of analyzing the efficiency value of eight projects by DEA method is described.

Among them, human input, cost input, SPI, CPI and quality performance indicators are derived from the actual production data of the project, and collected mainly from the engineering department, cost budget department, purchasing department, finance department, quality inspection department and other related functional departments. See Chapter V for the data sources of HSE management performance. Project codes in this chapter are corresponding to the previous text, and the actual production data of projects is shown in Table 6-3.

6.3.2 Data analysis

According to the actual production data of 8 projects shown in Table 6-3, the input and output indicator values of project efficiency evaluation can be calculated, as shown in Table 6-4. The change trend of evaluation indicators is shown in Figure 6-3.

Table 6-3 The actual production data of projects

Project type	Name	Unit	A	B	C	D	E	F	G	H
Human input	Managers	Person	39	25	41	33	20	24	33	27
	Technicians	Person	189	215	204	192	228	233	148	184
	Ordinary workers	Person	237	183	212	237	209	213	222	175
Cost input	Human cost	RMB10 thousand	1065	876	832	901	880	933	992	1148
	Material cost	RMB10 thousand	3214	4151	4715	4716	5087	4215	4231	4823
	Machinery cost	RMB10 thousand	986	1235	1426	1327	1556	898	1019	1221
	Other cost	RMB10 thousand	877	1752	663	987	558	423	909	337
SPI	Actual construction period	Month	14	18	15	16	15	16	13	15
	Planned construction period	Month	15	18	18	18	18	15	16	18
CPI	Actual cost	RMB10 thousand	6142	8014	7636	7931	8081	6469	7151	7529
	Planned cost	RMB10 thousand	5632	7211	7984	7656	7899	7517	8216	8515
Quality performance	Good rate of work package	Item	278	237	335	226	323	221	356	357
	Total volume of work package	Item	658	558	575	447	528	332	488	504

Table 6-4 Comprehensive efficiency evaluation indicator values for projects

Category	Name	Project A	Project B	Project C	Project D	Project E	Project F	Project G	Project H
Input indicators	Manpower input	465	423	457	462	457	470	403	386
	Cost input	6142	8014	7636	7931	8081	6469	7151	7529
Output indicators	SPI	1.07	1.00	1.20	1.13	1.20	0.94	1.23	1.20
	CPI	0.92	0.90	1.05	0.97	0.98	1.16	1.15	1.13
	Quality performance	0.42	0.42	0.58	0.51	0.61	0.67	0.73	0.71
	HSE management performance	2.89	3.49	3.45	3.38	3.3	3.69	3.77	4.15

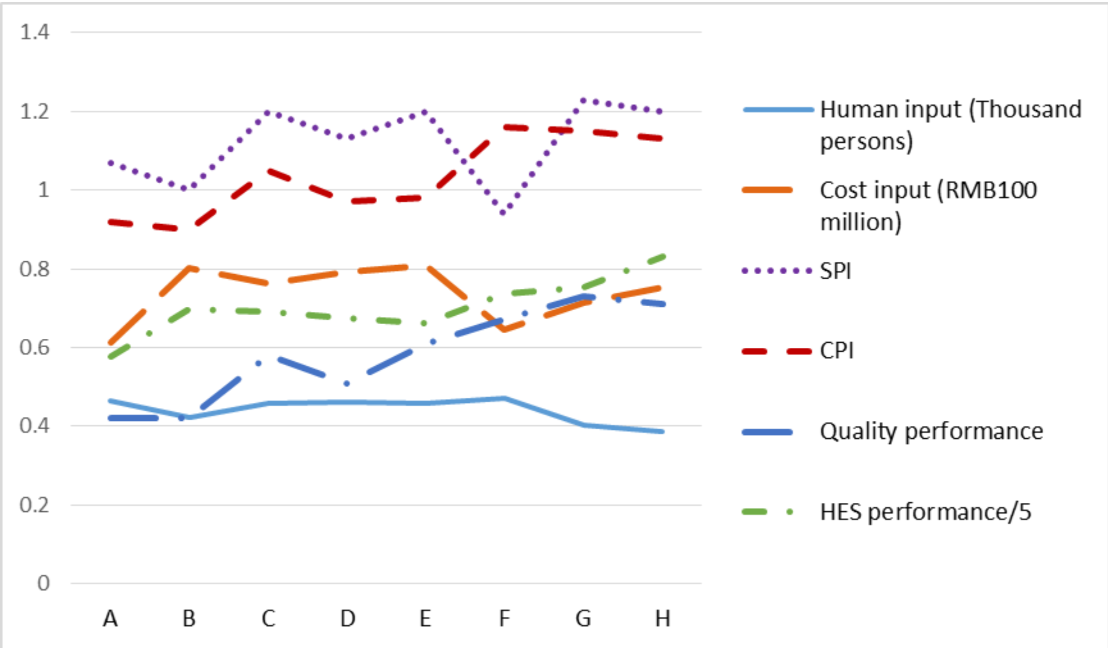

Figure 6-3 Chart of changing trend of evaluation indicators

In the aspect of input indicators, the manpower input for eight projects is between 386 and 470 people. Project H involved the least manpower (386 people) and Project C involved the largest manpower (470 people). The cost of the eight projects is between RMB 6142 and 8081. Project A involved the least cost (RMB 61.42 million), and Project E involved the highest cost (RMB 80.81 million). The cost of each of the eight projects was more than RMB 60 million, which fully reflects the characteristics of the capital-intensiveness of the engineering construction industry.

In the aspect of output indicators, the SPI of the eight projects was between 0.94 and 1.23. Among them, the SPI of Project F was the lowest (0. 94) and the SPI of Project G was the highest (1. 23). The SPI of projects A, C, D, E, G and H was greater than 1, which indicates that the six projects were completed ahead of schedule, the SPI of Project B was equal to 1, which indicates that the project was completed as planned, and the SPI of Project F was less than 1, indicating that the project was completed behind schedule. The CPI of eight projects was between 0. 90and1. 16, the CPI of Project B was the lowest (0. 90), and the CPI of Project F was the highest (1. 16). The CPI of projects C, F, G and H was more than 1, which indicates that the actual cost of the four projects was lower than the planned cost, and the cost target was achieved. The CPI of the four projects A, B, D and E was less than 1, which indicates that the actual cost of the four projects was higher than the planned cost, and the cost target had not been achieved. The quality performance of the eight projects was between 0.42 and 0.73. The performance of projects A and B was the lowest (0. 42) and that of Project G was the highest (0. 73). The results show that the excellent and good rate of the work package of Project A and B were the lowest, the quality control of projects G was the best, and the excellent and good rate of work package of projects G was the highest. Most of the above SPI, CPI and quality performance can reach the project goal, which shows that the enterprise has strong project management ability.

The efficiency evaluation indicator value is inputted into the DEA-C2R model, and its efficiency value can be obtained, as shown in Table 6-5.

Table 6-5 Project efficiency value based on DEA

Project	A	B	C	D	E	F	G	H
Efficiency value	1	0.788	0.912	0.827	0.863	1	1	1

As can be seen from Table 6-5, the efficiency value of the Projects A, F, G and H is 1, reaching the maximum value, which indicates that the input and output of these four projects are in the optimal state. The efficiency value of the Projects B, C, D, E is less than 1, which indicates that the input and output of the four projects fail to reach the optimal state, and their resource configuration should be optimized or their output increased to further enhance project efficiency.

In order to further analyze the input redundancy and output deficiency of the above eight projects, in this study projection analysis of the input and output of the eight projects was made using the DEAP software, obtaining the target value of these projects, as shown in Table 6-6 and Table 6-7.

Table 6-6 Projection analysis of project input indicators

Project number	Input					
	Human input			Cost input		
	Original value	Projection value	Difference value	Original value	Projection value	Difference value
A	465	465	0	6142	6142	0
B	423	333	90	8014	6316	1698
C	457	417	40	7636	6960	676
D	462	382	80	7931	6561	1370
E	457	394	63	8081	6976	1105
F	470	470	0	6469	6469	0
G	403	403	0	7151	7151	0
H	386	386	0	7529	7529	0

As shown in Table 6-6, from the point of input indicators, if the current output level remains unchanged, the human input of the Projects B, C, D and E is decreased by 90, 40, 80 and 63 persons respectively, and meanwhile the cost input of the Projects B, C, D and E is reduced by RMB16.98 million, RMB6.76 million, RMB 13.7 million and RMB11.05 million respectively, the current level of output can still be reached. At this time, the efficiency value of each project is 1, and the input and output level is at its best.

As shown in Table 6-7, from the perspective of output indicators, if the current input level remains unchanged, the CPI of the Projects B, C, D and E can be increased by 0.06, 0.06, 0.08 and 0.14 respectively; the quality performance of the Projects B, C, D and E can be increased by 0.18, 0.09, 0.14 and 0.1 respectively; the HSE management performance of the Projects C, D and E can be improved by 0.15, 0.04 and 0.37 respectively.

Table 6-7 Projection analysis of project output indicators

Project number			A	B	C	D	E	F	G	H
Output	SPI	Original value	1.07	1	1.2	1.13	1.2	0.94	1.23	1.2
		Projection value	1.07	1	1.2	1.13	1.2	0.94	1.23	1.2
		Difference value	0	0	0	0	0	0	0	0
	CPI	Original value	0.92	0.9	1.05	0.97	0.98	1.16	1.15	1.13
		Projection value	0.92	0.96	1.11	1.05	1.12	1.16	1.15	1.13
		Difference value	0	0.06	0.06	0.08	0.14	0	0	0
	Quality performance	Original value	0.42	0.42	0.58	0.51	0.61	0.67	0.73	0.71
		Projection value	0.42	0.6	0.67	0.65	0.71	0.67	0.73	0.71
		Difference value	0	0.18	0.09	0.14	0.1	0	0	0
	HSE management performance	Original value	2.89	3.49	3.45	3.38	3.3	3.69	3.77	4.15
		Projection value	2.89	3.49	3.6	3.42	3.67	3.69	3.77	4.15
		Difference value	0	0	0.15	0.04	0.37	0	0	0

To sum up, the original value of input and output indicators of the Projects A, F, G and H is consistent with their projection value, which conforms to the conclusion that the efficiency value of these four projects is equal to 1. The original value of B, C, D and E has a certain gap with the projection value, which is consistent with the conclusion that the efficiency value of these four projects is less than 1.

From the above analysis, it can be seen that the efficiency value of the Projects A, F, G and

H is 1, which cannot be further analyzed for analysis. The efficiency value of these four projects cannot be further sorted by using DEA-C2R model, and the project with the optimal efficiency value cannot be determined. Super-efficiency DEA model can sort decision-making units effective for DEA again by the method of secondary evaluation (Chen, 2004). Therefore, this study uses the model for secondary evaluation of the eight projects, so as to clarify the sorting of the efficiency value of eight projects. The efficiency value of the eight projects is shown in Table 6-8.

Table 6-8 Research on project efficiency based on super-efficiency DEA

Project	A	B	C	D	E	F	G	H
Efficiency value	1.012	0.788	0.912	0.827	0.863	1.115	1.081	1.149
Sorting	4	8	5	7	6	2	3	1

As can be seen from Table 6-8, the efficiency value of the eight projects is between 0.78 and 1.15. Among them, the efficiency value of the Project H is the highest, which is 1.149. The Project B has the lowest efficiency value of 0.788. The efficiency value of the eight projects is sorted in sequence: H>F>G>A>C>E>D>B, the results of which show that the input-output ratio of the project H is the highest, and the efficiency of the Project B needs to be further improved. The change trends of the efficiency value of the eight projects are shown in Figure 6-4.

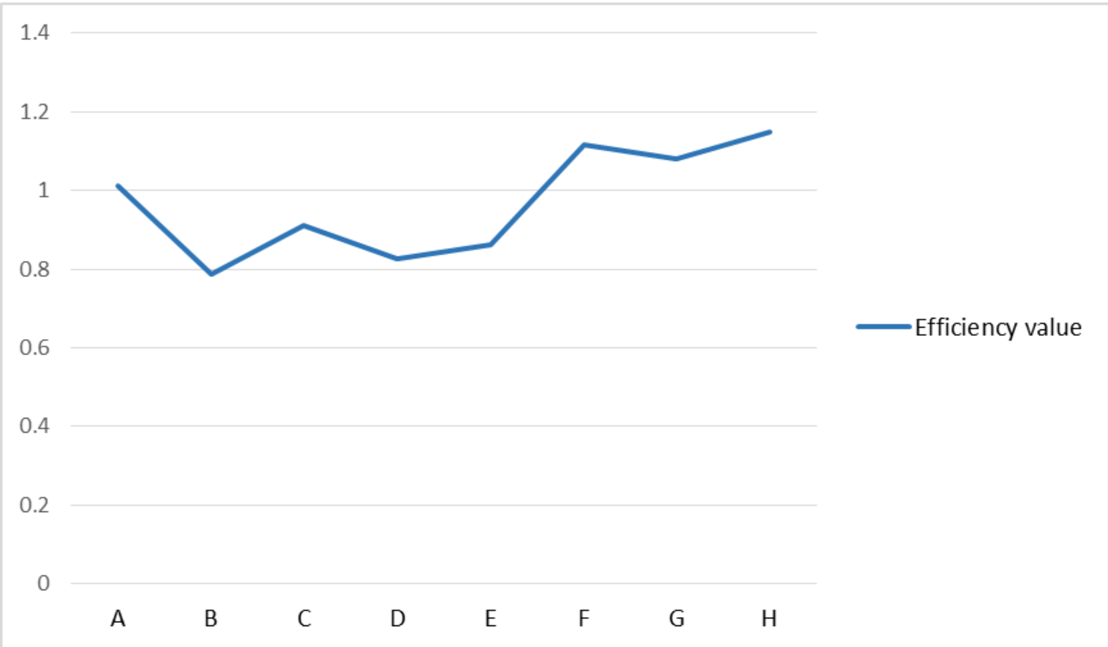

Figure 6-4 Change trends of the efficiency value of the eight projects

As shown in Figure 6-4, the eight projects advance over time on the horizontal axis, and the vertical axis represents project efficiency. The efficiency value of the eight projects implemented over time shows an increasing trend on the whole. The reason is that through the introduction of the HSE management system the Enterprise A has realized the improvement of the organization-level project management system, guaranteeing the gradual improvement of management level in the project implementation process.

6.4 Comparison and analysis of project efficiency and HSE management performance

The comparison between the change trends of the efficiency value and of the HSE management performance of the eight projects is shown in Figure 6-5. Both the efficiency of the eight projects and the HSE management performance show an increasing trend. The overall project efficiency shows an increasing trend after integrating the HSE management performance deeply into to the comprehensive system. The Enterprise A should strengthen the HSE management to further improve the project efficiency, thus improving the comprehensive management level of the enterprise.

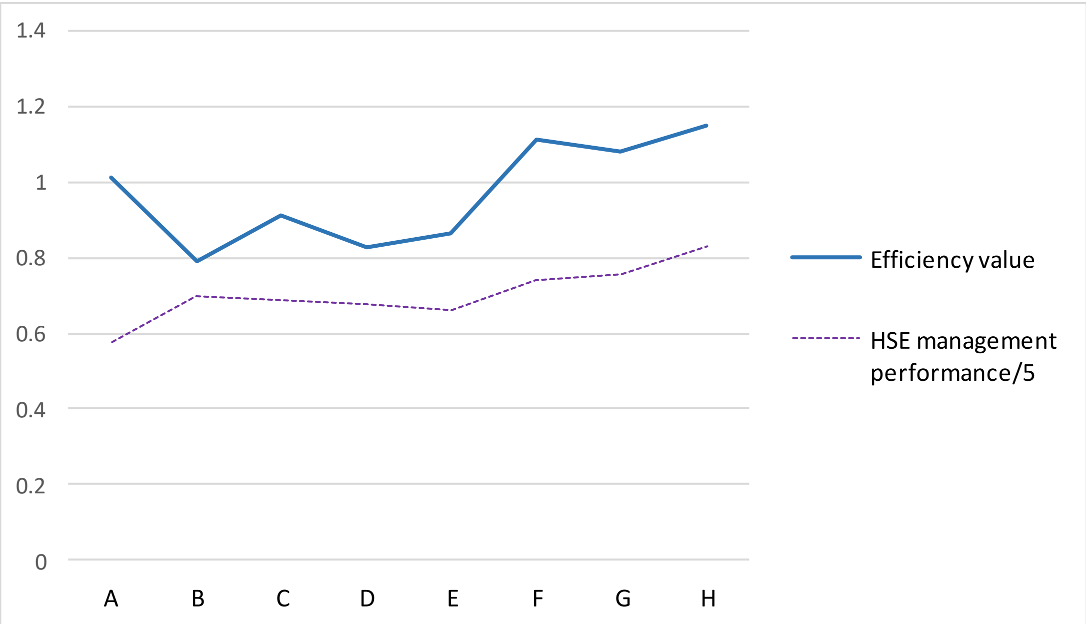

Figure 6-5 Comparison between the change trends of the project efficiency and HSE management performance

6.5 Summary of this chapter

In addition to traditional performance indicators such as SPI and CPI, this chapter also introduces HSE management performance indicators, and analyzes key factors, thus improving the evaluation method of project efficiency. Moreover, it selects eight construction projects to carry out empirical analysis, and expounds the process of analyzing project efficiency by use of the evaluation indicators constructed, so as to put forward management suggestions for improving project efficienc.

Chapter 7: Summary and Prospect

7.1 Summary

This dissertation discusses the HSE management system of construction projects and the HSE management performance evaluation methods from the perspective of project contracting enterprises, and further proposes the evaluation methods of project efficiency. To sum up, the following three conclusions are mainly drawn from the researches of this study:

(1) Through two rounds of questionnaire survey and interview, this study proposes the organization-level project HSE management system of project contracting enterprises. At the organization level, the implementation outline of HSE management is put forward, and the implementation details of HSE management brought forward at the project level, which provides a theoretical framework for improving the organization-level project management system of the enterprise.

(2) Using AHP to construct the management system evaluation indicators and obtain their relative weight, and proposing the quantitative evaluation methods of HSE management performance. The empirical analysis shows that the organization-level project HSE management system is effective.

(3) Putting forward the efficiency evaluation methods for construction projects. Output indicators contain SPI, CPI, quality performance and HSE management performance as well as other key indicators. Moreover, DEA-C2R model and super-efficiency DEA are used to calculate the efficiency value of eight projects. The empirical analysis results show that the improved project HSE management performance can improve the efficiency of the project.

The above research results help engineering contracting enterprises establish the perfect HSE management system, make up for the insufficiencies of the organization-level project management system of enterprises, be able to quantitatively evaluate project HSE management performance and efficiency, and optimize the management ability and organization-level project management level of enterprises. Furthermore, these research results can also be used for reference by enterprises in other industries for their HSE management system construction and project management.

7.2 Research prospect

From the perspective of engineering contracting enterprises, this study discusses the HSE management system construction, HSE management performance evaluation and project efficiency evaluation methods in the implementation phase of projects. In the dissertation there are still some limitations and specifically the following insufficiencies:

Large-scale construction projects need to go through many stages, such as planning, construction and operation, and they are closely related to each other. Therefore, by discussing HSE management from the perspective of the whole life cycle of projects, we can carry out the overall management of occupational health, safety and environment more comprehensively.

In a word, HSE management is currently the important management objective of large-scale construction projects. Project contracting enterprises should actively build up the scientific and reasonable HSE management system, and make great contribution to the sustainable development of the society.

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Appendix

Appendix 1 Questionnaire of Project HSE Management Performance Indicator Weight

The survey data is only used for academic research, and the answers to the questionaire are neither good nor bad. The questionnaire consists of 2 pages. Please fill it in carefully according to your opinion. Thank you for your participation and cooperation! (Note: This questionnaire is applicable to the engineers and management experts participating in the project as well as the senior management of the Enterprise A)

Questionnaire description: making a comparison between any two elements in the table and determining the relative importance. The scores are determined according to Table 1 (Analytic Hierarchical Process scoring criteria), and the corresponding scores are filled in the spaces in Table 2 ~ Table 5.

Table 1 Judgement matrix scale and its meaning

Scale	Definition
1	Comparision between i and j shows that these two elements are equally important
3	Comparision between i and j shows that i is slightly more important than j
5	Comparision between i and j shows that i is obviously more important than j
7	Comparision between i and j shows that i is quite more important than j
9	Comparision between i and j shows that i is extremely more important than j
2，4，6，8	Comparision between i and j shows that the importance of these two elements is the intermediate level of the above scale value
Reciprocal value	If the importance ratio of i to j is a_{ij}， then a_{ij}=1/ a_{ij}

Note: If A is more important than B and B is more important than C, then A is more important than C; due to the symmetry of the table, only the upper part of Tables 2, 3, 4 and 5 needs to be completed.

Table 2 Judgment matrix of criterion level factors

	Criterion level indexes	j: Occupational health management	Safety management	Environmental management
i	Occupational health management	1		
	Safety management	-	1	
	Environmental management	-	-	1

Table 3 Judgment matrix of occupational health management evaluation

	Criterion level indexes	j: Occupational health publicity	Psychological consultation	Medical service	Healthcare facilities	Pharmaceuticals and personal care products
i	Occupational health publicity	1				
	Psychological consultation	-	1			
	Medical service	-	-	1		
	Healthcare facilities	-	-	-	1	
	Pharmaceuticals and personal care products	-	-	-	-	1

Table 4 Judgment matrix of safety management evaluation

Criterion level indexes	j: Safety inspection at work	Interprocess safety acceptance	Machinery & equipment safety	Field fire protection management	Protection product guarantee	Safety accident handling

			management			
Safety inspection at work	1					
Interprocess safety acceptance	-	1				
Machinery & equipment safety management	-	-	1			
Field fire protection management	-	-	-	1		
Protection product guarantee	-	-	-	-	1	
Safety accident handling	-	-	-	-	-	1

Table 5 Judgment matrix of environmental management evaluation

Criterion level indexes		j					
		Reasonable site planning	Complete, tidy and clean living facilities	Complete site marks & signs	Closed worksite management	Placing of materials in good order	Timely pollutant disposal
i	Reasonable	1					

site planning						
Complete, tidy and clean living facilities	-	1				
Complete site marks & signs	-	-	1			
Closed worksite management	-	-	-	1		
Placing of materials in good order	-	-	-	-	1	
Timely pollutant disposal	-	-	-	-	-	1

Appendix 2 Score Sheet of Project HSE Management Performance Indicators

Thank you very much for filling in the questionnaire. The answers are neither good nor bad. Please choose the corresponding answer according to the actual situation of the project. All data is for academic research only. Please tick the corresponding level according to the actual HSE management of the project. Thank youyou’re your participation and cooperation! (Note: This questionnaire is applicable to the stakeholders of the projects)

Target level	Criterion level	Index level		Index grade
HSE management performance indicator system	Occupational health management (B1)	C11	Occupational health publicity	□Poor ☐Slightly poor ☐Average ☐Slightly good □Very good
		C12	Psychological consultation	□Poor ☐Slightly poor ☐Average ☐Slightly good □Very good
		C13	Medical service	□Poor ☐Slightly poor ☐Average ☐Slightly good □Very good
		C14	Healthcare facilities	□Poor ☐Slightly poor ☐Average ☐Slightly good □Very good
		C15	Pharmaceuticals and personal care products	□Poor ☐Slightly poor ☐Average ☐Slightly good □Very good
	Safety management (B2)	C21	Safety inspection at work	□Poor ☐Slightly poor ☐Average ☐Slightly good □Very good
		C22	Interprocess safety acceptance	□Poor ☐Slightly poor ☐Average ☐Slightly good □Very good

	C23	Machinery & equipment safety management	□Poor □Slightly poor □Average □Slightly good □Very good
	C24	Field fire protection management	□Poor □Slightly poor □Average □Slightly good □Very good
	C25	Protection product guarantee	□Poor □Slightly poor □Average □Slightly good □Very good
	C26	Safety accident handling	□Poor □Slightly poor □Average □Slightly good □Very good
Environmental management (B3)	C31	Reasonable site planning	□Poor □Slightly poor □Average □Slightly good □Very good
	C32	Complete, tidy and clean living facilities	□Poor □Slightly poor □Average □Slightly good □Very good
	C33	Complete site marks & signs	□Poor □Slightly poor □Average □Slightly good □Very good
	C34	Closed worksite management	□Poor □Slightly poor □Average □Slightly good □Very good
	C35	Placing of materials in good order	□Poor □Slightly poor □Average □Slightly good □Very good
	C36	Timely pollutant disposal	□Poor □Slightly poor □Average □Slightly good □Very good

Appendix 3 Achievements obtained in the process of pursuing a Doctoral degree

Dissertations published

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