Research on the Theory and Method of Power Grid Equipment Management Evaluation Under the Background of Energy Internet Enterprise Transformation

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Abstract—The internal and external environment of power grid enterprises has undergone profound changes, and some problems have emerged in the process of equipment management. With the aggravation of climate change and the increasingly serious environmental problems, energy transformation has received extensive attention. In order to achieve the dual carbon goal as soon as possible, it is necessary to vigorously promote the transformation of Internet energy. Energy transformation is a systematic project of fundamental changes in energy production and consumption structure, and a comprehensive optimization of energy production and consumption patterns. So, it is necessary to scientifically study and judge the situation, carry out the evaluation of power grid equipment management effectiveness, and systematically and comprehensively analyze the problems and deficiencies existing in the implementation of the system. This paper systematically combs the relevant theories of equipment management system construction and evaluation, so as to lay a foundation for the normalization of equipment management effectiveness evaluation and help decision makers fully grasp the status of equipment.

Keywords-theory and method; equipment management evaluation

1.INTRODUCTION

In recent years, many countries in the world are experiencing energy crisis, and the global energy system is facing severe challenges and uncertainties. In 2020, China formally proposed the goal of " striving to achieve carbon peak by 2030 and carbon neutrality by 2060 " at the 75th United Nations General Assembly, and began to take various effective measures to promote the realization of the " double carbon " goal. Promoting the transformation of energy Internet is an inevitable choice to get out of the energy crisis. It is necessary to build a green, low-carbon, efficient and safe energy system to get rid of the energy crisis.

With the great development of power grid equipment scale and operation inspection configuration, equipment management is also facing new requirements under the new situation and exposing some problems. The more typical problems are: the operation inspection mode of power grid is relatively backward, the health status of equipment cannot be fully and effectively mastered, and the on-line monitoring and live detection technology is not enough to support the

MSIEID 2023, December 08-10, Guangzhou, People's Republic of China

DOI 10.4108/eai.8-12-2023.2344459

long-term condition-based maintenance work, condition-based maintenance is generally in the primary stage of regular maintenance or preventive maintenance[1]. The risk response ability of "asset wall" needs to be strengthened[2]. The risk of "asset wall" formed by years of high-intensity and large-scale power grid construction has become increasingly prominent. The demand for equipment renewal and transformation has increased, the fault risk has accumulated, and the maintenance cost has increased. The implementation of asset life cycle management needs to be deepened. Life cycle management has been implemented for many years, but it is still not implemented in place in the specific management process[3]. It is necessary to further improve asset management objectives and strategies, strengthen asset condition monitoring, promote explicit production cost management, refine production cost analysis, promote the comparison and demonstration of project scheme life cycle cost (LCC), and continuously improve the quality and efficiency of power grid asset operation[4]. There are signs of hollowing out in basic business.

Equipment management system optimization is a management activity to implement the whole process of equipment management system construction[5]. It is necessary to attach great importance to the optimization and improvement of equipment management system. Through the evaluation of power grid equipment management effectiveness, take evaluation as the starting point, promote improvement through evaluation, analyze the key problems and difficulties existing in the equipment management system, systematically and comprehensively analyze the problems and deficiencies existing in the implementation of the system, and optimize the power grid equipment management system, further clarify the specific work to support the safer, higher quality, more efficient and more sustainable development of power grid enterprises.

2.ANALYSIS OF RELEVANT THEORIES OF EQUIPMENT MANAGEMENT SYSTEM

2.1TnPM five-level six-dimensional evaluation system

TnPM (Total Normalized Productive Maintenance) is a standardized TPM. Based on the study of TPM (total normalized productive maintenance) management system, Professor Li Baowen of Guangzhou University proposed a new equipment management mode suitable for China's national conditions and enterprise reality. In order to promote the implementation of TnPM in enterprises, a five-level and six-dimensional evaluation system of TnPM is proposed to carry out effectiveness evaluation, which is convenient for enterprises to objectively understand the equipment management level.

1) The content of TnPM five-level six-dimensional evaluation

TnPM five-level and six-dimensional evaluation system is a tool and method to help enterprises test the level of equipment management. Among them, five-level refers to the evaluation level and six-dimensional refers to the evaluation field. Based on the six-value logic, the five-level evaluation level is divided into 1-5 levels to reflect the equipment management level of the enterprise, which can truly and objectively reflect the situation of the enterprise. The evaluation results are classified according to the ladder. Through the ladder level, enterprises can understand their level in the industry and the goals they need to continue to strive for. The six dimensions represent the evaluation fields, including the soundness of organizational structure, production site conditions, employee literacy, standardization of management process,

knowledge assets and information management, efficiency and cost indicators of equipment management, etc. Pay attention to both result indicators and process indicators, and follow the management concept that good results are process oriented. Through the comprehensive evaluation of processes and results, enterprises clearly understand their main problems and the gap with high-level objectives.

a) The rank of five-level evaluation

The progress of enterprise TnPM is gradual and stepwise. The evaluation of equipment management system is defined as six value logic, that is, the evaluation system from zero-level to fifth-level. The zero-level representative fails to pass the step-in review. The first level is the primary level, and the fifth-order is the highest level. The total score of TnPM five-level six-dimensional evaluation standard is 1000 points. The score division corresponding to the five level is shown in table 1.

TABLE 1. FIVE-LEVEL SCORE TABLE

Level	Score
5	971~1000
4	901~970
3	801~900
2	671~800
1	501~670

b) Field of six-dimensional evaluation

The content of TnPM five-level six-dimensional evaluation is divided into six modules, including organization dimension, specification dimension, execution dimension, information dimension, employee dimension and performance dimension. The six dimensions and their corresponding scores are shown in Figure 1. The specific evaluation contents are as follows:

The first is the organizational dimension, which evaluates the soundness of the organizational structure, focusing on whether the enterprise has a sound and reasonable equipment management organization and TnPM promotion organization, whether each grass-roots production department has a supporting promotion organization, and whether the organizational activities are active.

The second is the normative dimension, which evaluates the standardization of management process, focusing on whether the enterprise has concise and optimized equipment maintenance strategy, maintenance mode and maintenance resource allocation design; Whether there are equipment operation and production process operation instructions (operation specifications) at the production site; Whether there are operation instructions for maintenance specifications and management closed-loop process instructions; Whether each link has corresponding time commitment; Whether there are safety protection and environmental protection treatment processes for emergencies; Whether the inspection and maintenance department has maintenance process operation instructions (maintenance code of conduct) covering main equipment. The standardization of management process should also involve many aspects, such as equipment early-stage management, material and spare parts management, technical transformation management, asset information management and so on.

The third is the implementation dimension, which evaluates the status of the production (Work) site, focusing on the implementation of the requirements of each module of the equipment on the site, as well as the fixed location management status of the production site and whether there is a fixed location map; Visual management of production site, whether production, equipment, safety, health and environment are included in visual management, and whether the visual board is lively.

The fourth is information dimension, which evaluates information and knowledge asset management, focusing on the application scope of computer management in the field of equipment management and the establishment, coverage and implementation of knowledge management system in the field of equipment maintenance.

Fifthly, the staff dimension is to evaluate the staff growth and team building, focusing on whether the activities of the team are active, whether the staff participate in the proposal (reasonable proposal), the proportion of monthly proposals in the number of employees, the implementation rate of the proposal, and the recognition of the staff to the system.

The sixth is the performance dimension, which evaluates the economic indicators of equipment management, paying attention not only to the absolute value of the indicators, but also to the relative progress, the scientific and completeness of the indicator design, etc. the evaluated equipment management indicators include the comprehensive efficiency of the equipment, the fully effective productivity, the proportion of maintenance cost in production cost, the maintenance cost per unit output, the proportion of spare parts capital in equipment assets, the turnover rate of spare parts working capital, the average failure interval Average maintenance preparation time, average maintenance time, maintenance damage rate, etc.

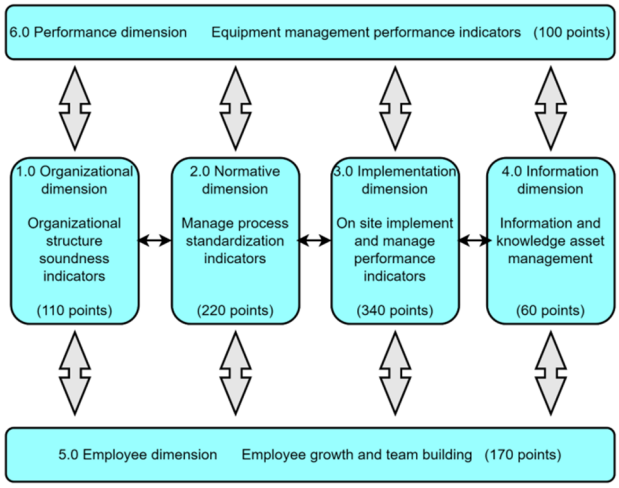

Figure 1. six-dimension and score distribution

2) Five-level and six-dimensional evaluation criteria of TnPM

The five-level and six-dimensional evaluation criteria of TnPM is shown in Figure 2. The six arrows divide the spatial area into six blocks, representing the six evaluation indicator groups, also known as six dimensions; The five closed circles represent five stairs, which are closed in

the innermost circle, representing no breakthrough and in the most basic state; Breaking through the innermost layer, that is, the first circle, indicates that the enterprise level has entered the first level, and breaking through the outermost layer, that is, the fifth circle, indicates that the enterprise has entered the fifth level and reached the five-star level.

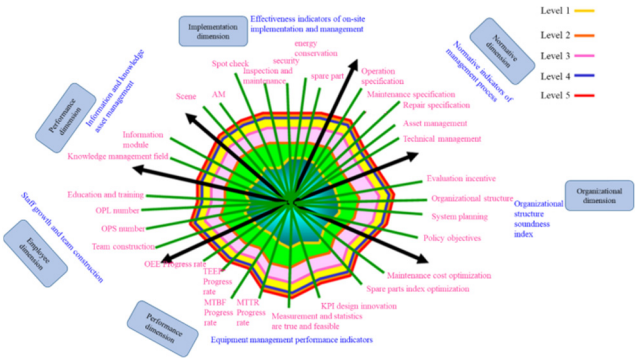

Figure 2. General diagram of five-level six-dimensional evaluation criteria of TnPM

2.2Excellent performance model evaluation system

As a set of comprehensive and systematic business performance management mode, excellent performance mode provides a systematic quality management framework for enterprises. It can be used to evaluate the maturity of enterprise management, guide enterprises to build a perfect comprehensive performance management system, and find their own advantages and existing problems. Its ideas and methods can be used for reference in the construction of equipment management system. The excellent performance model is mainly composed of six process categories and one result category, including leadership, strategy, customer and market, resources, process management, measurement, analysis and improvement. The relationship and logical relationship between them are shown in Figure 3.

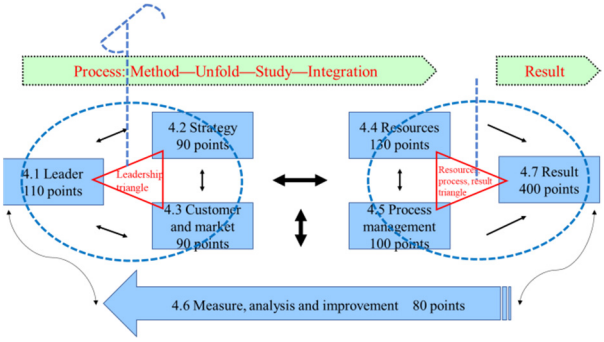

Figure 3. Excellent performance model evaluation system

1) Scoring rules of excellent performance model

The excellence performance evaluation criteria include 7 categories (6 process categories such as leadership, strategy, customer and market, resources, process management, measurement,

analysis and improvement and 1 result), and are subdivided into 23 scoring terms (which can be scored separately at the level of scoring terms), with a total score of 1000. The specific contents and scores of the terms are shown in Table 2.

TABLE 2. CONTENT EXPANSION AND SCORE DISTRIBUTION OF PERFORMANCE EXCELLENCE EVALUATION CRITERIA

Category	Scoring clause	Score	Total (1000)
4.1 Leadership	4.1.2 Role of senior leadership	50	110
	4.1.3 Organizational governance	30	
	4.1.4 Social responsibility	30	
4.2 Strategy	4.2.2 Strategy formulation	40	90
	4.2.3 strategic deployment	50	
4.3 Customer and market	4.3.2 Customer and market understanding	40	90
	4.3.3 Customer relationship and customer satisfaction	50	
4.4 Resources	4.4.2 Human resources	60	130
	4.4.3 Financial resources	15	
	4.4.4 Information and knowledge resources	20	
	4.4.5 Technical resources	15	
	4.4.6 infrastructure	10	
	4.4.7 Related party relationship	10	
4.5 Process management	4.5.2 Process identification and design	50	100
	4.5.3 Implementation and improvement of process	50	
4.6 Measurement, analysis and improvement	4.6.2 Measurement, analysis and evaluation	40	80
	4.6.3 Improvement and innovation	40	
4.7 Result	4.7.2 Product and service results	80	400
	4.7.3 Customer and market results	80	
	4.7.4 Financial results	80	
	4.7.5 Resource results	60	
	4.7.6 Process effectiveness results	50	
	4.7.7 Leadership results	50	

2) Evaluation method of excellent performance model

Excellence performance evaluation includes qualitative evaluation and quantitative scoring. It can not only give qualitative comments on the advantages and improvement opportunities of the organization according to the requirements of the excellent performance evaluation criteria, but also give quantitative scores according to the scoring guidelines to evaluate the maturity level of organization management. In most practical evaluations, the two can be used together, which are generally divided into process type and result type.

"Process" evaluation refers to the organization's evaluation of the scoring terms. The evaluation method adopted is to evaluate the maturity of the organizational process according to the four elements of "Approach-Deployment-Learning-Integration" (ADLI). According to the requirements of the standards, the four elements of the process are used to evaluate the process scoring terms of the organization with reference to the process scoring guide. The key points of the evaluation are shown in Table 3.

TABLE 3. PROCESS EVALUATION ELEMENTS

Essential factor	Key points of evaluation
Approach (A)	The suitability of the method, including the requirements for standard scoring terms and the actual suitability of the organization.
	Whether the effectiveness of the method lead to good results.
	The systematism of the method, including repeatability and the degree based on reliable data and information.
Deployment (D)	Whether the method continuously applied.
	Whether the method applied in all applicable departments.
Learning (L)	Through cyclic evaluation and improvement, the method is continuously improved.
	Encourage breakthrough changes in methods through innovation.
	Share the improvement and innovation of methods in relevant departments and processes.
Integration (I)	The methodology is consistent with the organizational needs identified in the organizational overview and other scoring terms.
	Measurement, information and improvement systems complement each other throughout the process and work units.
	Plans, processes, results, analysis, learning and actions are coordinated throughout the process and work units to support the organization's strategic objectives.

"Result" evaluation refers to the output and effect obtained by the organization according to the scoring terms in 4.7 results in the performance excellence evaluation criteria. Use the four elements of "Levels-Trends-Comparisons-Integration" (LeTCI) results to evaluate the maturity of organizational performance results. According to the requirements of the criteria, the four elements of results are used to evaluate the results scoring terms of the organization with reference to the results scoring guide. The key points of evaluation are shown in Table 4.

TABLE 4. RESULT EVALUATION ELEMENTS

Essential factor	Key points of evaluation
Levels(Le)	Current level of organizational performance
Trends(T)	Speed of organizational performance improvement (slope of trend data)
	Breadth of organizational performance improvement (extent of expansion)
Comparisons(C)	Performance comparison with suitable competitors or similar organizations
	Performance against benchmarking or industry leaders
Integration(I)	The measurement indicators of organizational results correspond to the key performance requirements and indicators determined in the scoring terms of "organization Overview" and "process"
	The results of all processes and departments of the organization are coordinated to support the realization of the organization's mission, vision and strategic objectives

3) Evaluation form of excellent performance model

Excellent performance evaluation generally includes data review and on-site review. The review mainly evaluates the self-evaluation report submitted by the organization or the actual operation

status of the organization one by one according to the excellent performance evaluation criteria. After the review, a comprehensive report and item-by-item report will be formed. The comprehensive report is mainly for the senior leaders of the organization to explain the advantages and improvement opportunities of the organization; The item-by-item report is a comment prepared item by item according to the requirements of the excellent performance evaluation criteria, which is convenient for the organization to deeply understand the specific advantages and improvement opportunities in all aspects.

3. PRACTICE OF TYPICAL ENTERPRISES

This part focuses on the evaluation practice of Baosteel's equipment management system and the group operation ability of State Grid Corporation, so as to provide beneficial enlightenment for the construction of power grid equipment management evaluation system.

3.1Evaluation practice of equipment management system of Baosteel in China

China Baosteel Co., Ltd. (hereinafter referred to as Baosteel) is the most competitive iron and steel enterprise in China. It has formed a mature equipment management system, which is widely imitated and innovated by domestic iron and steel enterprises. Baosteel Group mainly adopts TPM equipment management mode to promote the construction of equipment management system. Through extensive investigation and research and in combination with Baosteel's equipment management practice, Baosteel Group provides a set of overall management framework and self-evaluation criteria for comprehensively improving Baosteel's equipment comprehensive management ability, and formulates The Comprehensive Evaluation Standard of Baosteel's Equipment Management System on the basis of absorbing international advanced equipment management ideas, That is, the comprehensive evaluation standard with equipment and man-machine system as the main line.

The Comprehensive Evaluation Standard of Baosteel's Equipment Management System according to the ten aspects concerned, the evaluation elements and evaluation guidelines of each evaluation dimension are clarified, and the evaluation results are divided into five levels (the first level is the primary level and the fifth level is the highest level), and the evaluation guidelines of each level are described in detail. Taking the equipment management performance evaluation as an example, it is required to establish the equipment management performance evaluation system to evaluate the maintenance process and results and improve the management efficiency. The evaluation elements and evaluation guidelines are shown in Table 5.

TABLE 5. THE COMPREHENSIVE EVALUATION STANDARD OF BAOSTEEL'S EQUIPMENT MANAGEMENT SYSTEM-- EQUIPMENT MANAGEMENT PERFORMANCE EVALUATION

Evaluating Indicator	Assessment Element	Level	Evaluation guide
Equipment Management	(1)A standardized equipment management performance evaluation	Level 1	(1) The performance evaluation system of equipment management is established; (2) Performance analysis of equipment management process is not carried out.

Performance Evaluation	system should be established; (2) Carry out performance analysis of equipment management process, focusing on equipment status, spot inspection effect, fault cause, actual performance of function and accuracy, implementation of regular maintenance plan and control of maintenance cost; (3) There should be performance improvement measures; (4) Each management level above the operation area shall hold an equipment management performance analysis meeting or seminar once a month. Each department shall analyze the management performance and report it at the management seminar at the next higher level; (5) The performance evaluation results are organically combined with incentives to effectively guide the progress of equipment management.	Level 2	(1)A standardized equipment management performance evaluation system is established; (2) The performance analysis of equipment management process is not focused enough, and the performance improvement measures are not targeted; (3) Irregularly schedule hold performance analysis meetings or seminars.
		Level 3	(1) Carry out the performance analysis of equipment management process, focus on the weak links, and the performance improvement measures are highly targeted; (2) Each management level above the operation area shall hold an equipment management performance analysis meeting or seminar once a month.
		Level 4	(1) Each management level above the operation area shall hold an equipment management performance analysis meeting or seminar every month, have the analysis of management performance, and be able to report at the management seminar of the next higher level; (2) The performance improvement measures are highly targeted, and the effectiveness is verified after the measures are implemented; (3) The combination of performance evaluation results and incentive is not close, which cannot effectively guide the progress of equipment management.
		Level 5	(1) Performance evaluation results are closely combined with incentives, which can effectively guide the progress of equipment management; (2) Through performance evaluation, the effect of guiding organizational progress is obvious.

3.2Evaluation on the effectiveness of group system construction of State Grid Corporation

State Grid Corporation proposes to build a group management and control system. In order to evaluate the construction effect, it constructs an evaluation system from the aspects of evaluation dimension, evaluation grade and evaluation process, so as to clarify the system construction and existing problems.

1) Effectiveness evaluation dimension of collectivization system construction

With the help of maturity management concept, the evaluation of group operation ability of State Grid Corporation constructs an evaluation index system from eight dimensions: organizational structure level, strategic control ability, power grid operation ability, resource

allocation ability, business coordination ability, basic management ability, high-quality service ability and risk prevention and control ability.

TABLE 6. EVALUATION INDEX SYSTEM OF COLLECTIVIZATION OPERATION ABILITY

Target	Primary index	Secondary index
Group operation ability	Organizational structure level	Organization simplification rate
	Strategic management and control capability	Strategic planning capability
		Operation monitoring capability
		Plan execution ability
	Grid operation capacity	Power grid planning level
		Power grid construction level
		Power grid operation optimization capability
		Power grid operation and maintenance capacity
	Resource allocation capability	Intensive management level of core resources
		Utilization level of external resources
		Extensive provisioning capabilities
	Business collaboration capability	Collaborative service level
		Asset life cycle management level
	Basic management ability	Standardization and normative level
		Systematized management: comprehensiveness and seriousness
		Information support capability
		Corporate culture identity
	Quality service capability	Power supply quality
		Serving customers
	Risk prevention and control ability	Operational risk prevention and control capability
		Power grid risk prevention and control capability
		Emergency capacity

2) Stage division of evaluation index

The evaluation indexes of State Grid Corporation's collectivization operation ability include both qualitative and quantitative indexes. For each index, its ability level can be divided into five levels, namely start, foundation, development, optimization and excellence. The qualitative indicators are scored by experts, and 0-0.9 points are the status before management; 1-1.9 it is classified as "starting" stage; 2-2.9 classified as "foundation" stage; 3-3.9 classified as "development" stage; 4-4.9 divided into "optimization" stage; 5 points to reach the "excellence" stage. For quantitative indicators, take the worst value of the indicator since the establishment of the company and the best value that the indicator may obtain, divide it into five equal divisions, and then divide each grade into 10 scoring intervals, and convert the quantitative indicators into grade indicators. After weighted average, the collectivization operation capability level of State Grid Corporation is obtained.

TABLE 7. STAGES AND LEVELS OF COLLECTIVIZATION OPERATION CAPABILITY

Stage	Group operation capability level
start	Understand and agree with the concept of power grid enterprise group operation, and show corresponding awareness in some work;
foundation	Infrastructure construction began sporadic attempts and practices in some fields of highly collectivized operation of the company;
development	Began to implement management reform in a planned and organized way and developed towards the goal of group operation;
optimization	It has a mature group operation mechanism, obtains significant benefits from organization flattening, resource intensification, business specialization and management synergy, and continuously optimizes itself in daily operation;
excellence	Highly collectivized operation has been formed, which has obtained differentiated competitive advantages. At the same time, it leads the development direction in the industry and occupies a leading position in international operation.

4.EXPERIENCE ENLIGHTENMENT

4.1Establish the evaluation mechanism of equipment management system to form closed-loop management

Equipment management system evaluation is a management activity implemented in the whole process of equipment management system construction. Power grid enterprises need to establish an evaluation mechanism for the construction effect of equipment management system, take evaluation as the starting point, form a PDCA cycle, promote the continuous improvement and efficient operation of modern equipment management system, and continuously improve the overall level of power grid equipment management.

4.2Carry out systematic evaluation of "process + result" to promote comprehensive improvement

Through the analysis of theory and practice, it is found that the standard of *Equipment Management System Requirements* emphasizes that we should pay attention to both results and process; Baosteel adheres to the purpose of paying more attention to results and process evaluation when designing the evaluation standard of equipment management system. Therefore, when constructing the evaluation index system of modern equipment management system, it is necessary to comprehensively consider the process and results and carry out systematic evaluation.

4.3Scientifically and reasonably divide the evaluation level and clarify the system construction stage

Evaluating the effectiveness of power grid equipment management is an important part of building and improving the power grid equipment management system, which can promote the continuous improvement and improvement of equipment management. The effectiveness evaluation of power grid equipment management needs to be based on the changes of the internal and external environment of power grid enterprises, focus on the key problems of power grid equipment management, learn from the relevant theories of management system evaluation,

focus on the specific measures of power grid enterprise equipment management, pay attention to the research and construction of power grid equipment management evaluation system, comprehensively and objectively evaluate the management effectiveness and find the existing problems and deficiencies, so as to point out the direction for optimizing the power grid equipment management system.

5.POWER GRID EQUIPMENT MANAGEMENT EVALUATION APPLICATION

In order to implement the modern equipment management system, it is necessary to construct a scientific and reasonable equipment management evaluation index system to characterize the construction of the modern equipment management system. According to the experience of typical companies, the State Grid Corporation selects the evaluation indicators from two aspects: process evaluation and result evaluation. The process part mainly focuses on the annual key actions of the equipment management system, and the part mainly focuses on qualitative and quantitative evaluation. The result evaluation is the comprehensive embodiment of the equipment management process and management level, mainly around the quantitative objectives of the equipment management system, this part is mainly quantitative evaluation.

In this paper, six provincial companies in Gansu, Hunan, Zhejiang, Fujian, Liaoning and Chongqing were selected as the research objects, and the data were collected by questionnaire for empirical analysis.

From the comprehensive level, the comprehensive evaluation results of the six provincial companies were 80.54, 87.04, 93.46, 90.71, 89.41 and 76.04, respectively, all at a good level (the scores were all higher than 75 points). Due to differences in regional endowment, management basis and economic status, the equipment management level in different regions was unbalanced. The level of equipment management in economically developed areas is relatively high. Since the process evaluation of the project is mainly self-evaluation by the company in each province, the evaluation results are biased due to factors such as subjective evaluation and inconsistent scale. However, the ranking of the comprehensive evaluation results is consistent with the actual ranking of the equipment management development of each unit mastered by the company, indicating that the constructed equipment management evaluation model has strong credibility.

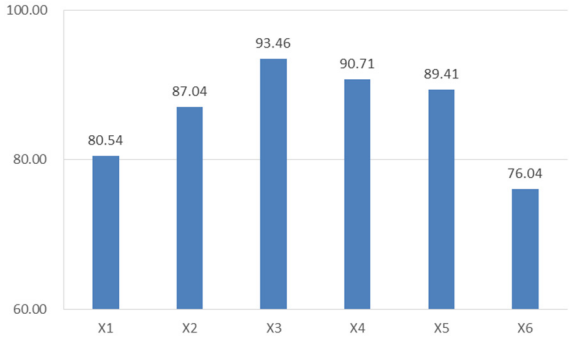

Figure 4. Comprehensive evaluation results of modern equipment management system construction

6.CONCLUSION

The evaluation of the effectiveness of modern equipment management system construction is a complex systematic project, which involves many factors and a wide range. By analyzing related theories and practices of management system evaluation, this paper finds that most management evaluations are carried out from two aspects: process evaluation and result evaluation. For example, the performance excellence model evaluates enterprise management maturity from two dimensions: process and result. Baosteel adheres to the purpose of attaching importance to results and paying more attention to process evaluation when designing evaluation standards for equipment management system. This project adopts the evaluation mechanism combining process evaluation and result evaluation to evaluate the effectiveness of equipment management of six provincial power grid companies.

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