Construction of the Effectiveness Evaluation System for Digital Transformation of Power Grid Enterprises

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Abstract. In response to issues such as incomplete indicators and unreasonable subjective and objective weight settings in the existing enterprise digital transformation effectiveness evaluation model, a digital transformation effectiveness evaluation model for power grid enterprises is proposed. Considering the key factors influencing the digital transformation of power grid enterprises, an indicator system for the evaluation model of digital transformation effectiveness is constructed. By utilizing the Analytic Hierarchy Process (AHP) and entropy weight method, the subjective and objective weights of the evaluation indicators are calculated. On this basis, by incorporating the concept of dynamic feedback and applying the panel threshold model, the proportion of subjective and objective weights is deeply integrated with the dynamic objectives of the corresponding stages, greatly improving the accuracy of the evaluation results. Case studies show that this model can achieve dynamic adjustment based on the objectives of each stage, ensuring the accuracy of the evaluation results of the digital transformation effectiveness of power grid enterprises, and providing decision support and theoretical support for optimizing the digital transformation route of power grid enterprises.

Keywords: power grid enterprises; digital transformation; effectiveness; evaluation model; dynamic feedback

1 INTRODUCTION

With the acceleration of the information technology revolution, data has become a new driving force for economic development. In recent years, against the backdrop of a new round of technological and industrial revolution, the digital economy has emerged as a new high ground for competition among countries. Consequently, our country has made important deployments such as Digital China, Energy Revolution, digital transformation of central enterprises, carbon peaking and neutrality goals. In response, power

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grid enterprises, as large-scale enterprises possessing vast amounts of critical data, have also made the significant decision to embark on a digital transformation.

The digital transformation of power grid enterprises is a necessary path to promote energy transformation and align with the dual carbon goals. Through measures such as intelligent upgrades of the power grid, coordinated interaction between energy sources, grids, loads, and storage, the access capacity for renewable energy, distributed power sources, and microgrids is enhanced, accelerating the transformation of the power grid towards an energy internet and achieving high-quality development for power grid enterprises. Comprehensively and systematically grasping the laws of transformation, accurately positioning the current level and grade of digital transformation effectiveness in enterprises, and clarifying the direction, goals, and paths for leapfrogging to higher development levels and grades have become imperative questions for enterprise survival and development. Although new technologies and theories related to digital transformation are emerging in an endless stream, research on the evaluation system for digital transformation effectiveness is still relatively scarce. Therefore, there is an urgent need to explore an evaluation system that combines digital transformation practices with theories at this stage.

2 FRAMEWORK FOR EVALUATING THE EFFECTIVENESS OF DIGITAL TRANSFORMATION IN POWER GRID ENTERPRISES

The overall structure of the evaluation framework aims to integrate the five dimensions of business digitization, digital industrialization, digital foundation, digital safeguard system, and digital effectiveness evaluation. Meanwhile, under the dimension of digital foundation conditions, we clarify three underlying elements: digital resources, digital technologies, and digital ecosystems; under the dimension of digital safeguard systems, we consider four strategic safeguards: talent, security, organizational transformation, and institutional innovation; under the dimensions of business digitization and digital industrialization, we evaluate the transformation of infrastructure, business applications, and business models; and finally, under the dimension of digital effectiveness evaluation, we comprehensively consider efficiency, benefits, and the overall contribution rate of digitization.

3 CONSTRUCTION OF THE EVALUATION INDICATOR SYSTEM FOR THE EFFECTIVENESS OF DIGITAL TRANSFORMATION IN POWER GRID ENTERPRISES

Focusing on strengthening the foundation for digital development, promoting the digital transformation of businesses, actively expanding digital industrialization, and enhancing digital safeguard capabilities, an evaluation indicator system for digital effectiveness has been established, which comprises eight primary indicators, 34 secondary indicators, and 114 tertiary indicators as the main content.

3.1 Construction of Middle and Cloud Platforms

As the construction of business, technology, and data middle platforms bridges the gap between the backend and frontend of power grid enterprises, enabling more efficient business operations and management, and cloud platform construction facilitates big data computing and storage for enterprises, the setting of this primary indicator aims to measure the integration capabilities of production materials and the construction level and capabilities of cloud computing infrastructure during the digital transformation process of power grid enterprises. Secondary indicators include the degree of construction of business middle platforms, the degree of construction of technology middle platforms, the degree of construction of data middle platforms, and the digital construction and management of cloud platforms.

3.2 Foundation of Data Management and Services

The establishment of this indicator aims to evaluate the enterprise's data management capabilities and its application enhancement. Data, as the most fundamental element in the digitization process, will have different sub-indicators set based on its various roles within the enterprise. Considerations can be made from aspects such as data collection, storage, computation, and transmission. Additionally, a secondary indicator evaluating the effectiveness of data management capabilities will be included for a comprehensive assessment.

3.3 Foundation of Production Digitization

The primary indicator aims to assess the role of digitizing production processes in strengthening grid management, building an intelligent management system, and establishing a new model of coordinated control. Considering the enabling effect of production digitization on grid production, this indicator also serves to measure the level of digital transformation in grid production. Sub-indicators include digital production monitoring, the digitization level of power business, the efficiency of integrated grid scheduling operations, digital management of manufacturing processes, and the level of collaboration based on digital manufacturing.

3.4 Foundation of Customer Service Digitization

This primary indicator evaluates the digitization level of different types of services provided by grid enterprises when facing the market and customers. The digitization level of customer service is positively correlated with service quality and efficiency, meaning that a higher digitization level corresponds to higher service quality and convenience.

The foundation indicator of customer service digitization also evaluates the ability to empower customer service, which is primarily composed of the construction of intelligent marketing systems and integrated power market service platforms. Therefore, secondary indicators should be set from the perspective of intelligent marketing systems and integrated power market service platform construction, while also including the digitization level and satisfaction of customer experience to evaluate the completeness of customer service.

3.5 Foundation of Management Digitization

The establishment of this primary indicator aims to assess the enabling effect of management digitization on enterprise operations and management, thereby measuring the level of digital transformation in grid enterprise operations. Further assessments are made from multiple dimensions such as financial auditing, human resources, and integrated smart supply chains.

3.6 Integration and Upgrading of Digital Industries

The establishment of this primary indicator aims to evaluate the integration level of the grid enterprise's own energy value chain and the enabling role of grid enterprise digitization in emerging industries. This serves to measure the structural reorganization capabilities and industrial driving capabilities of grid enterprise digitization.

3.7 Construction of Digital Security System

The establishment of this primary indicator aims to evaluate the grid enterprise's ability to ensure safety and stability during the digitization process, and to assess the strengthening of enterprise security protection, technological leadership, and operational support. Overall indicator settings should comprehensively consider the completeness of digital security system construction from four aspects: leadership institutions, security protection construction, operational management mechanisms, and enterprise IT architecture.

3.8 Digital Performance

The establishment of this primary indicator aims to provide a final quantitative assessment of the enterprise's overall digitization level, thereby measuring changes in economic and social benefits during the digitization process of grid enterprises. The setting of secondary indicators considers the overall efficiency and benefits of power enterprises as well as the comprehensive benefit contribution rate under the digital model.

4 EVALUATION MODEL FOR THE EFFECTIVENESS OF DIGITAL TRANSFORMATION IN POWER GRID ENTERPRISES

The existing evaluation models require optimization in terms of the determination of indicator weights, which fail to make dynamic adjustments according to phased development goals. This hinders the long-term applicability of the evaluation model and is inconsistent with the constantly changing objective reality of enterprises. To enhance the accuracy of the evaluation, this paper adopts a dual-indicator approach, combining subjective and objective weights to form a comprehensive weight through a dynamic ratio. This dynamic ratio varies with the development objectives of each stage, allowing the evaluation results of the digital transformation effectiveness in power grid enterprises to adjust dynamically with technological advancements.

4.1 Calculation of Subjective Weights

Based on the subjective characteristics of power grid enterprises' strategic level, the Analytic Hierarchy Process (AHP) is employed to stratify the evaluation objectives into three levels: decision-making level, criterion level, and objective level, resulting in a hierarchical structure model as shown in Figure 1. Assuming there are m evaluation objectives and n indicators, the evaluation indicators in Section 3 are factorized (see Figure 1).

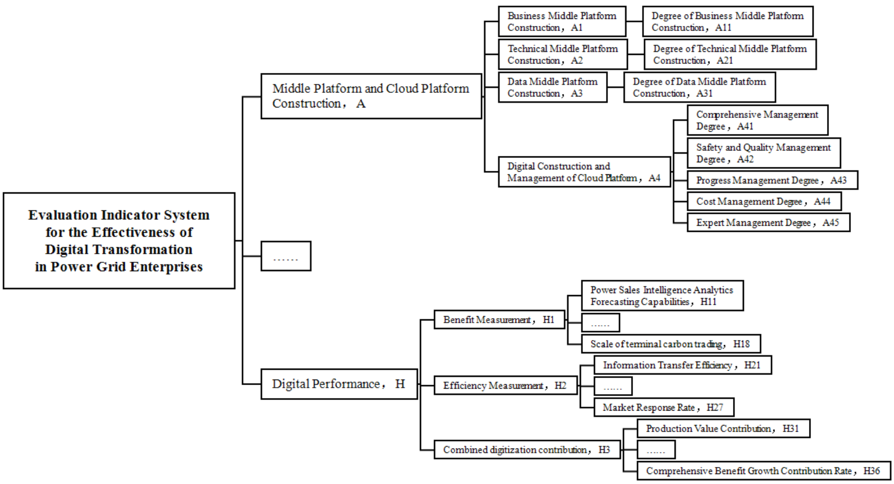

Fig. 1. Hierarchical Structure for Evaluating the Effectiveness of Digital Transformation in Power Grid Enterprises

On the basis of hierarchical stratification, detailed evaluation calculations can be obtained through the following steps:

1. Establish a judgment matrix $\mathbf{A}^{(k)}$ based on the elements of each level. The judgment matrix objectively illustrates the importance of each element, assigning importance levels using a 1-9 scale, resulting in the judgment matrix:

$$\mathbf{A}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

2. Calculate the weight of each indicator. Using the judgment matrix, the weight of each factor is calculated by obtaining the eigenvector corresponding to the maximum eigenvalue, $w_j^{(k)}=\left(w_1^{(k)},w_2^{(k)},\cdots,w_n^{(k)}\right),\quad j=1,2,\cdots,n$.
3. Consistency check. A consistency check is conducted based on the obtained weight values of each factor. When the consistency ratio meets a certain criterion $C_{\mathrm{R}}<0.10$, the judgment matrix is considered valid; otherwise, corrective measures are taken.
4. Establish an initial evaluation matrix. An initial evaluation matrix $X=\left[x_{ij}\right]_{m\times n}$ is established based on the evaluation indicator system for the effectiveness of digital transformation in power grid enterprises, where x_{ij} represents the measured value of element i in the objective level regarding evaluation indicator j.
5. Calculate the normalized evaluation matrix $\mathbf{Y}$. Since the selected evaluation indicators have different dimensions, they need to be dimensionless to make them comparable. Therefore, an evaluation matrix $\mathbf{Y}=\left[y_{ij}\right]_{m\times n}$ is established, where $y_{ij}=\sqrt{x_{ij}/\sum_{i=1}^{m}x_{ij}^2}$ represents the normalized values.

4.2 Calculation of Objective Weights

Given the objectivity of the measurement data corresponding to the evaluation indicator system for the effectiveness of digital transformation in power grid enterprises, the entropy weight method is employed to express the differences among various indicators and calculate their respective weights.

Entropy, originally derived from thermodynamics in physics, is often used in non-physical contexts to represent the degree of chaos within a system. It quantifies the uncertainty within a system. Currently, entropy has been widely applied in information, society, economy, and other fields.

In information theory, entropy measures the degree of chaos in a system, while information measures the degree of order. They have equal absolute values but opposite signs. In an indicator data matrix $\mathbf{Y}=\left[y_{ij}\right]_{m\times n}$ composed of m evaluation targets and n evaluation indicators, the greater the dispersion of data, the smaller the information entropy, and the greater the amount of information provided. This indicator has a greater impact on comprehensive evaluation, and its weight should be greater accordingly. Conversely, the smaller the difference among indicator values, the greater the information entropy, the smaller the amount of information provided, and the smaller the impact of the indicator on the evaluation results, with a correspondingly smaller weight. Determining indicator weights using the entropy method can overcome the randomness and speculation inherent in subjective weighting methods while effectively resolving information overlap among multiple indicator variables.

Using the normalized initial matrix $\mathbf{Y}$ established in Section 4.1 to obtain the evaluation indicator value P_{ij}, combined with information entropy theory, the objective weight values of different indicators can be obtained $e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} P_{ij} \ln P_{ij}$. In equation, the actual value P_{ij} of the evaluation indicator should be between 0 and 1, derived from the dimensionless processing of the original data $\left(y_{ij}\right)$ and the calculation of the indicator proportion $\left(p_j\right)$. The calculation method is $P_{ij} = \frac{y_{ij}}{p_j \cdot y_{j\max}}, \quad i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots, n$, where $p_j = \sum_{i=1}^{m} y_{ij}; y_{j\max} = \max_i \left\{y_{ij}\right\}$ represents the calculation details. Additionally, if $P_{ij} = 0$, it is conventionally agreed that $\ln P_{ij} = 0$. The difference coefficient of different indicators is calculated based on entropy, as shown in equation $d_j = 1 - e_j$. Accordingly, the weights corresponding to each indicator are given as $\omega_j = \frac{d_j}{\sum_{k=1}^{n} d_k}$, resulting in an objective weight vector $\mathbf{W}_{\text{EN}} = \left(\omega_1, \omega_2, \ldots, \omega_n\right)$ based on the entropy weight method.

4.3 Comprehensive Evaluation Calculation Based on Dynamic Feedback

Based on the subjective weight vector $\mathbf{W}_{\text{AHP}}$ and objective weight vector $\mathbf{W}_{\text{EN}}$ obtained from sections 4.1 and 4.2, the comprehensive evaluation index weight vector $\mathbf{W}$ can be initially determined. Furthermore, let θ_0 represent the initial proportion of subjective weight in the comprehensive weight, leading to the calculation formula for the evaluation index weight vector, as shown in $\mathbf{W} = \left(w_1, w_2, \ldots, w_n\right)^{\text{T}} = \theta_0 \cdot \mathbf{W}_{\text{AHP}} + \left(1 - \theta_0\right)\mathbf{W}_{\text{EN}}$.

Generally, the accuracy of the evaluation model gradually decreases with changes in digital technology. Therefore, the focus of this paper is on how to set dynamically changing index weight values. To this end, variable subjective and objective weight proportions are set for different stages of development to improve the accuracy of the final evaluation results. When the difference between the actual evaluation result value and the target value for a certain stage exceeds a certain threshold δ, dynamic adjustments will be made to the subjective weight proportion. The greater the gap between the actual value and the ideal value, the less the digitalization effectiveness of the enterprise has reached the standard, and the corresponding objective weight proportion should be increased accordingly. This is because objective weights can better reflect factual evidence, making the improved evaluation results more reflective of the actual digitalization effectiveness of the power grid enterprise. Therefore, the comprehensive evaluation algorithm based on dynamic feedback is as follows: $\mathbf{W}=(w_1,w_2,\mathrm{L},w_n)^{\mathrm{T}}=\theta_0\cdot\mathbf{W}_{\mathrm{AHP}}+(1-\theta_0)\mathbf{W}_{\mathrm{EN}}$

In the formula, θ represents the subjective weight proportion after dynamic adjustment, and its specific expression is as follows:

$$\theta=\theta_0\left[\left(1-\frac{\left|\alpha_l-\sum_{i=1}^{m}\sum_{j=1}^{n}\omega_{ij}s_{ij}\right|}{\alpha_l}\right)\times I\left(\alpha_l-\sum_{i=1}^{m}\sum_{j=1}^{n}\omega_{ij}s_{ij}\geqslant\delta\right)+I\left(\alpha_l-\sum_{i=1}^{m}\sum_{j=1}^{n}\omega_{ij}s_{ij}<\delta\right)\right] \tag{1}$$

Where: α_l is the expected digitalization effectiveness evaluation target value for stage l; s_{ij} is the score of a level 3 indicator under a level 1 indicator of a certain power grid enterprise; $\sum_{i=1}^{m}\sum_{j=1}^{n}\omega_{ij}s_{ij}$ is the initial comprehensive evaluation value; $I(\cdot)$ is an indicator function, taking 1 when the corresponding condition is met and 0 when it is not met.

4.4 Case Analysis

Taking the Electric Power Company of H Province (hereinafter referred to as "H Company") as the analysis object, this paper adopts the evaluation algorithm and model of digital transformation effectiveness in power grid enterprises based on dynamic feedback to comprehensively evaluate the development and construction of smart grids in various cities in the region during the "14th Five-Year Plan" period. Since the evaluation model in this paper dynamically changes with the targets of different stages, the stage of H Province's power grid up to the end of 2023 is selected as the research object to calculate the digitalization effectiveness evaluation value of H Company, and a questionnaire is designed accordingly. To ensure that the questionnaire can accurately measure the implementation level of digital transformation in power grid enterprises, evaluation questions are established for each level 3 indicator. For each question, participants need to select the option that best matches the current status of the enterprise from five options, thereby obtaining the score for that indicator (corresponding to 0-40, 41-60, 61-80, 81-90, 91-100 points).

The digitalization effectiveness of power grid enterprises can be divided into five stages based on the score: 0-40 points indicate the embryonic stage of digitalization, where the enterprise's digitalization projects are in the preparatory stage, and managers are paying attention to the development prospects of digitalization; 41-60 points represent the growth stage of digitalization, where the enterprise matches digitalization strategies to the development needs of digitalization and conducts intelligent transformation of infrastructure; 61-80 points represent the mature stage of digitalization, where digital transformation work is basically completed, and the digitalization needs of the power grid are basically met; 81-90 points represent the leading stage of digitalization, where digital transformation work is comprehensively deepened, and transformation achievements are applied and implemented on a large scale; 91-100 points represent the excellent stage of digitalization, where digitalization needs are fully met, and the enterprise has even become a benchmark for other enterprises in the industry to learn from.

Table 1. Weights and Scores of Level 1 Indicators in the Evaluation Model of Digital Transformation Effectiveness for H Company

No.	Primary Indicators	Weight	Score
1	Middle Platform and Cloud Platform Construction	0.09	71
2	Foundation of Data Management and Services	0.06	67
3	Foundation of Production Digitization	0.16	77
4	Foundation of Customer Service Digitization	0.15	74
5	Foundation of Management Digitization	0.16	77
6	Integration and Upgrading of Digital Industries	0.11	71
7	Construction of Digital Security System	0.12	83
8	Digital Performance	0.15	81

Table 1 shows the weights and scores of level 1 indicators in the evaluation model of digital transformation effectiveness for H Company. The evaluation score of H Company's digitalization effectiveness during the case period is 76.07, indicating that it is in the mature stage of digitalization, which aligns with H Company's goals for the 2023 stage. This also suggests that H Company has developed a relatively comprehensive digital strategy plan and conducted intelligent transformation of its infrastructure, but further deepening of digital development is still needed. Future power grid enterprises need to carry out deeper digital transformations and strengthen the development of weak indicators such as data management and service foundations, as well as digital industry integration and upgrading.

5 CONCLUSION

Based on the above analysis, this paper combines the digital transformation development needs and realistic conditions of power grid enterprises to refine the evaluation index system for digital transformation effectiveness. From a quantitative analysis perspective, based on the calculated effectiveness scores and scores of each level 1 indicator, it is possible to intuitively grasp the dialectical relationship between the whole and parts in the digitalization process of power grid enterprises, identify weaknesses and pain points, formulate corresponding improvement plans, and take targeted measures to continuously promote the sustainable and healthy development of power grid digitization. From a qualitative analysis perspective, power grid enterprises can clarify the logical relationship of digital transformation, fully leverage the driving role of data in the digitalization process to achieve the transformation of digital capabilities, strengthen evaluation and diagnostic capabilities during the process, continuously optimize strategic decisions and practical activities for digital transformation, and ultimately achieve the digitization of enterprise value.

In addition, based on the actual situation of digital transformation in power grid enterprises, this paper uses the analytic hierarchy process to calculate subjective weights. Considering the fact-based characteristics of objective weights, the entropy weight method is applied to calculate objective weights, greatly enhancing the comprehensiveness of the weight calculation scheme. By adopting the panel threshold model, the subjective and objective weight proportions are deeply integrated with the targets of each stage, ensuring the comprehensiveness of evaluation indicator selection while improving the dynamic relationship between subjective and objective weight proportions and the targets of each stage, thereby further enhancing the accuracy of the evaluation results of digital transformation effectiveness.

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