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Research on Driving Factors of Collaborative Integration Implementation of Lean-Green Manufacturing System with Industry 4.0 Based on Fuzzy AHP-DEMATEL-ISM: From the Perspective of Enterprise Stakeholders

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Abstract: The existing research and practices have shown that the coordinated implementation of lean-green manufacturing can have a positive impact on the economic and environmental benefits, which is an effective means to ensure the environmental protection of the production process of manufacturing without damaging their profitability. Within the field of lean-green research, there is still a lack of research to analyze the driving factors for the collaborative implementation of integrated lean and green integration. Although, some scholars and researchers have studied lean and green integration paradigms, their research has mostly focused on lean-green integration practices and their impact on environmental performance and their respective operations. In the context of Industry 4.0, this article investigates the driving forces behind the collaborative integration implementation of a lean-green manufacturing system from the viewpoint of stakeholders. Specifically addressing the issues of correlation and ambiguity in the identification of driving factors, this manuscript proposes an Interpretation Structure Model (ISM) of fuzzy comprehensive Analytic Hierarchy Process (AHP), based on Decision-Making Trial and Evaluation Laboratory (DEMATEL), to determine the importance of the driving factors. Combined with the complex network theory, the evaluation index system is divided into four levels from eight factor categories, including endogenous lean-green driving factors and exogenous driving factors. The fuzzy AHP-DEMATEL-ISM is used to analyze the relationship between indicators and the structure of the indicator system. The complex network which is composed of the indicator system is divided into different levels. The importance of indicators is analyzed from the perspective of the global network, and key factors affecting the driving of lean-green system is analyzed. The integration of the lean-green manufacturing system and organizational synergy are promoted to jointly lead the enterprise toward sustainable development by paying particular attention to the primary impact indicators and aggressively cultivating the key impact indicators.

Keywords: driving factors; lean-green manufacturing; Industry 4.0; fuzzy AHP-DEMATEL-ISM; enterprise stakeholders

1. Introduction

Smart manufacturing/Industry 4.0 is going to be the future development trend of manufacturing enterprises [1]. In the various stages of the implementation of Industry 4.0, each sector of the manufacturing industry in various nations will have its own major directions and development aspects [2]. The core feature of the industrial internet in the United States, Germany's Industry 4.0 strategy, and made in China 2025 is interconnection, the essence of which is to shift from economies of scale to economies of scope through the automated flow

of data, and to build out heterogeneous and customized industries at a homogeneous and scaled cost, thus promoting the reform of industrial structure [3–8]. According to the data compiled by some of the scholars, Chinese manufacturing companies have great enthusiasm and expectation for Industry 4.0. A total of 76% of Chinese manufacturing companies believe that the use of Industry 4.0 strategy will greatly enhance the competitiveness of manufacturing industry, compared to 54% in the United States, 51% in Japan, and a low of 47% in Germany [9]. Chinese manufacturers are indeed very enthusiastic about Industry 4.0 and have high expectations for it, yet there are significant concerns and challenges with its implementation. While interviewing Chinese manufacturing companies, only 53% of them said that they are fully prepared for Industry 4.0 strategy, compared to 71% and 68%, in the US and Germany, respectively. Among them, state-owned enterprises are the most conservative, only 44% of the surveyed state-owned enterprises said that they are ready for Industry 4.0 strategy; the proportion of private manufacturing enterprises is as high as 68% [10]. One of the reasons is that the digital foundation for the development of intelligent manufacturing is relatively weak. The development of manufacturing industry as a whole is still in the transition stage from mechanical automation to digital automation. As far as the Industry 4.0 is considered in Germany as a reference system, the overall is still in the 2.0 era, but some enterprises are moving towards the 3.0 era. Therefore, most of China's manufacturing industry still needs to use lean management to reduce costs and increase efficiency, as well as use Industry 4.0 technology to upgrade and transform. Lean management is the soft aspect of overall optimization of manufacturing and management processes; while intelligent manufacturing is the hard aspect of intelligent upgrading of production factors and information systems. Chinese manufacturing companies must combine "hard and soft" and employ lean management to build a strong foundation for manufacturing companies to execute smart manufacturing in this wave of global manufacturing transformation and upgrading.

The rapid development of industry and the excessive use and waste of resources by human beings have led to the depletion of resources. In addition, a large amount of industrialized production also causes environmental pollution [11]. Existing manufacturing methods are causing climate warming and resource depletion, and are unsustainable. In order to solve this global challenge, Industry 4.0 is developed. Therefore, the first connotation of Industry 4.0 is to be smart, green, lean, and humanized. The pursuit of personalized items is gradually becoming more and more challenging for traditional production methods to generate personalized or customized products in large quantities due to the changing needs of consumers. The smart factory in Industry 4.0 environment aims to produce precise, high-quality, and personalized smart products, so that the efficiency and cost of single-piece small batch production can reach the same level of mass production. It can be customized for enterprise customers in large scale and small batch, and also for individual users in small batch and single product. The logistics and transportation system from raw materials to final products is completed by intelligent logistics. The lean production method is a great way to produce high quality and low consumption, under mixed production conditions of multiple varieties and small batches. Green first term refers to the use of alternative, non-traditional clean energy. It can reduce traditional energy consumption, effectively alleviate resource depletion, but also produces fewer pollutants, meaning effective protection of the environment. No matter how a product is made, its use and disposal have little effect on the environment across its entire life cycle, and they could be recovered and repurposed to promote sustainable development. Therefore, lean management and green manufacturing are the cornerstones for digital transformation to bring benefits. At the same time, John et al. (2021) showed that the goal of implementing lean-green manufacturing in manufacturing companies is at the same time the goal to be achieved by Industry 4.0, where lean-green manufacturing promotes a more time-efficient and resource-efficient of Industry 4.0 factory, which in turn further enhances lean-green manufacturing [12]. It can help substantiate this theory: the integration of lean-green manufacturing into the same framework in an Industry 4.0 context.

In summary, it is crucial for manufacturing companies to integrate and collaborate on the implementation of lean-green manufacturing systems in the process of Industry 4.0 transformation and upgrading. However, the lack of confidence and preparedness of Chinese manufacturing companies regarding the Industry 4.0 strategy is largely due to two major challenges: high-quality development, and improving total factor productivity. Therefore, it is necessary for the vast majority of manufacturing companies in China to determine how to integrate the collaborative implementation of lean-green manufacturing systems in a smart manufacturing/Industry 4.0 scenarios, and what are their drivers and relationships. In order for effectively collaborative integration implementation of lean-green manufacturing system under Industry 4.0, this research framework addresses the following research questions:

Question 1. *What are the drivers for integrated and collaborative implementation of lean-green manufacturing systems?*

Question 2. *What are the most critical drivers?*

Question 3. *What is the cause-and-effect relationship between them?*

Question 4. *What are the steps that need to be taken to better motivate these drivers to work? How about to achieve the goal?*

In the context of Industry 4.0, this manuscript analyzes the driving factors for collaboratively integrating the implementation of a lean-green manufacturing system. Aiming at the uncertainty and correlation problems in the process of driving factors identification, this study proposes an Interpretation Structure Model (ISM) of fuzzy comprehensive Analytic Hierarchy Process (AHP), based on decision making trial and evaluation laboratory (DEMATEL) to determine the importance of the driving factors. Combined with the complex network theory, the evaluation index system is divided into four levels from eight categories of factors, including endogenous lean-green driving factors and exogenous driving factors. The fuzzy AHP-DEMATEL-ISM is used to analyze the relationship between indicators and the structure of the indicator system, and the complex network composed of the indicator system is divided into different levels. The importance of indicators is analyzed from the perspective of the global network, and the important factors and key factors affecting the driving of lean-green system are analyzed. By paying special attention to the main impact indicators and actively cultivating the key impact indicators, the lean-green manufacturing system integration and synergy of the organization are promoted to jointly drive the enterprise to achieve sustainable development.

The paper consists of five parts. The rest of the paper is structured as follows: Section 2 presents the analysis of the driving factors of collaborative integration implementation of lean-green manufacturing system. The research methodology is discussed in Section 3, followed by a presentation of the case study in Section 4. In the last section, some conclusions are drawn.

2. Analysis of the Driving Factors of Collaborative Integration Implementation of Lean-Green Manufacturing System

There have been related research conducted by foreign scholars on the integrated implementation of lean-green manufacturing, for example, Mittal et al. (2017) proposed a new manufacturing strategy for manufacturing companies to increasing customer choice, address environmental issues in the manufacturing process and enhance their own competition among global manufacturers, thus adopting a lean-green-agile manufacturing system to coordinate trade-offs to meet the economic, environmental and social demands of modern manufacturing systems [13]. A recent study by Teresa et al. (2022) used a questionnaire to verify the operational, environmental, and financial performance of manufacturing companies implementing lean and green practices in Portugal, ultimately confirming that the

widespread adoption of lean and green practices produced better overall operational, environmental and financial performance, and that the integrated implementation of lean and green management practices in companies resulted in superior return on investment [14]. A new paradigm of lean-green manufacturing is made possible by the Industry 4.0 era in the manufacturing sector. Industry 4.0 can be understood as digital lean with an emphasis on green. That is to say, there will always be pressure to raise standards of productivity, quality, agility, environmental friendliness, and customer service in order to stay profitable and competitive in today's corporate environment. Lean-green manufacturing is the foundation for achieving smart factories. A comprehensive review of the lean-green literature by the author team and related scholars in this paper indicates that there is a lack of research to analyze the drivers of integrated lean-green integrated synergistic implementation [15–20]. Several scholars and researchers have studied the integration paradigm of lean and green, and their research has mainly focused on the practical approach of the integration of lean and green and its impact on operational and environmental performance. Some scholars have also studied the internal barriers to the implementation of lean-green manufacturing, and have taken countermeasures to eliminate the existing barriers [18–20]. The corresponding initiative is to study and activate the drivers of lean-green manufacturing system implementation in order to better collaborate and integrate the development of these systems.

The existing literature has confirmed the conclusion that the core concept of lean manufacturing is the creation of value and the elimination of activities that do not add value to the product in the manufacturing process. The lean model is seen to reduce waste, reduce costs, improve quality and productivity, make better use of resources, and create value for customers. The green manufacturing is designed to reduce negative environmental risks and impacts throughout the product life cycle process, while increasing resource productivity and eliminating environmental waste in the organization. The overlap (synergy) between lean-green manufacturing models consists of the following common attributes: waste and manufacturing process waste reduction or elimination techniques, people and organization, lead time reduction and thus production cycle time reduction, supply chain relationships, KPI: service levels and other specific practices. The main commonality between the two can be found in the target attributes of waste elimination and waste reduction in manufacturing processes. The waste (waste) reduction techniques of the two advanced manufacturing models, lean-green, are often similar, with a focus on operational and production practice processes. Both lean and green manufacturing models look at how to integrate product and process redesign to extend product life, make products easily recyclable and make processes more efficient (i.e., reduce waste). The development and success of improvement projects during the lean-green manufacturing model practices require a high level of employee involvement, encouragement of employee participation and empowerment of responsibility to streamline the realization of lean and green practices. When it comes to supply chain relationships, both models rely on close collaboration with supply chain partners, with collaboration supporting the sharing of information and best practices across the chain to serve the goal of an integrated supply chain.

While the two have much in common, there are also incompatible differences between lean-green. Green manufacturing is now no longer optional for manufacturing companies and by introducing green practices into a lean operating environment will have to make certain trade-offs between multiple objectives that are not entirely compatible. The differences between lean and green practices are: their focus, what is considered waste, customers, product design and manufacturing strategy, end of product lifecycle, KPIs, costs, key tools used, and certain specific practice approaches, for example, replenishment frequency, where lean emphasizes multiple batches and multiple frequencies, whereas there is an inconsistency in green's emphasis on reducing carbon emissions.

Lean-green manufacturing systems are an emerging area of research in the introduction and implementation of modern advanced manufacturing models in manufacturing

enterprises. Therefore, the integration of lean and green manufacturing models is an important part of the sustainable development of enterprises, especially in the context of China's manufacturing industry, which has become a supporting industry, and there is a need to explore and study the integration of lean and green manufacturing systems in the context of China's economic development and the current situation of enterprise operations. Lean-green manufacturing's integrated and collaborative implementation is driven by both endogenous and exogenous factors, which together drive the company to achieve sustainable development. Endogenous lean-green drivers include managers and internal employees. However, to study the synergistic effect generated by the integrated implementation of lean-green manufacturing also requires exogenous driving elements including shareholders, upstream and downstream companies, consumers, competitors, the public, and government agencies, which can be used as four levels for dividing evaluation indicators (or evaluation indicators can be divided into four categories).

The drive intensity evaluation indicators were divided into categories according to the different types of elements in the endogenous and exogenous green drives. It should be especially noted that since these indicators are derived from published research results, their scientific validity and effectiveness have been widely accepted by experts and scholars. These identified evaluation indicators are both scientifically valid and systematically comprehensive. The above factor indicators can be illustrated in Figure 1.
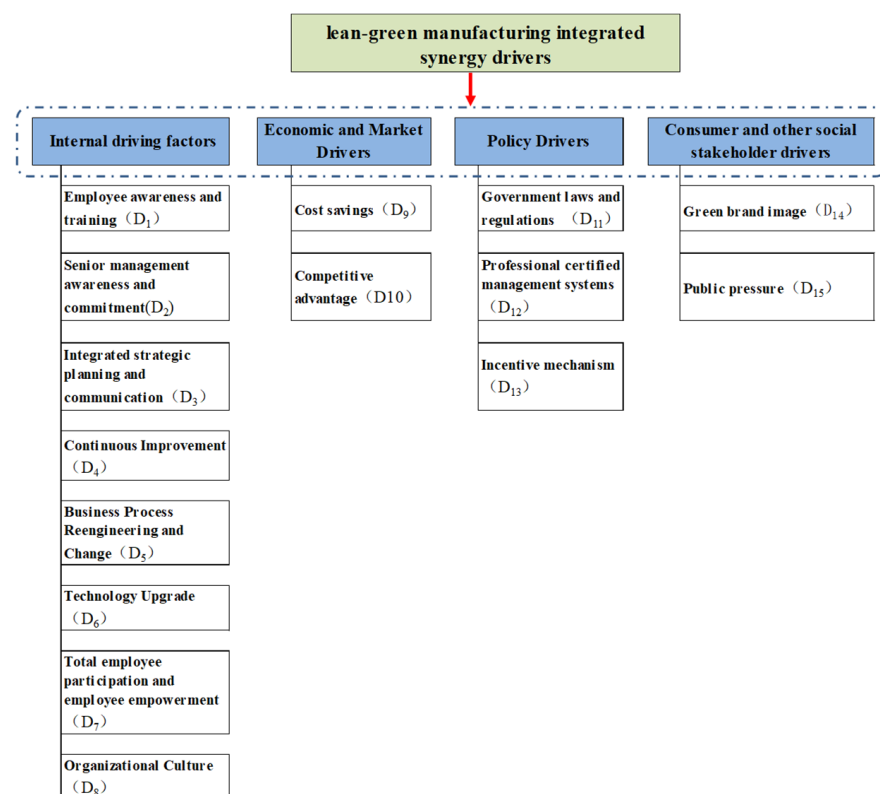
Figure 1. Classification of lean-green manufacturing integrated synergy drivers.

In today's highly competitive global environment, business organizations need to improve not only their operational performance but also their eco-efficiency. This has led many scholars to explore the possible merging and convergence of the lean and green paradigms, which in the traditional approach to business organization management practices are often implemented separately and deployed to achieve different corporate strategic goals. Dozens of corresponding papers were found through the corresponding databases (Elsevier, Springer, Emerald, Google Scholar, T&F, Wiley, IEEE, etc.) that delve into the compatibility, synergies, and success key indicator systems between the two. In terms of the search strings, they are specified based on the main topics of the phenomena under

investigation. Thus, we searched strings with titles, abstracts, keywords, and articles from January 1997 to 30 September 2022, including (lean green), (lean Industry 4.0), (green Industry 4.0), (lean-green Industry 4.0), (lean environment), (lean environmental), and (lean sustainability). The driver indicators in this thesis are sourced from existing research papers. In the schematic diagram of the classification of driver evaluation indicators shown in Figure 1, the specific meaning of each evaluation factor indicator is as follows.

2.1. Internal Driving Factors

Managers and enterprises are directly driven by external pressure, or by their own awareness of the management benefits of carrying out lean and green manufacturing, or they can also be driven by the spontaneous actions of internal employees based on their awareness of environmental efficiency and cost of their own economic and environmental interests.

Employee awareness and training (D_1): Awareness and acceptance of the Lean-green concept by employees within the company and the company's training to raise awareness of Lean-green among internal employees [15,18,20–23].

Senior management awareness and commitment (D_2): Awareness and public support from senior management and their commitment to the long-term competitive advantage of lean and green management in the company [18,22–28].

Integrated strategic planning and communication (D_3): The extent to which top management incorporates lean manufacturing, green production, and environmental protection into its planning; the degree to which middle and lower-level managers are aware of and support the application of lean-green; and the level of collaboration between corporate departments to advance lean-green management [15,19,23–30].

Continuous Improvement (D_4): Using lean-green tools for continuous improvement to solve internal problems and continuous improvement to eliminate waste, improve efficiency, reduce costs, etc., and lead to business sustainability and reduce the seven major wastes in the lean-green domain [15,18,20–28].

Business Process Reengineering and Change (D_5): Lean and green thinking is a useful strategy for streamlining business operations. Lean and green tools help companies to follow and use globally accepted methods and standards, to promote the streamlining of business processes, and fit the requirements of organizational lean and green change [15,18,19,26–33].

Technology Upgrade (D_6): Using energy and resource efficient advanced technologies to achieve production technology, equipment performance, and product performance that meet environmental requirements and industry leading levels [25,28,34–38].

Total employee participation and employee empowerment (D_7): Manufacturing companies attempting to build lean and green enterprises need all employees to share responsibility for all business functions, all employees to review and suggest ideas to solve problems that arise in business operations, and companies to motivate and empower employees to carry out lean and green project improvement activities in their daily business activities and provide institutional and financial support [15–48].

Organizational Culture (D_8): Establish a dynamic company culture that is open to new concepts and management models, and create a good work environment and atmosphere that promotes lean-green initiatives [31,35,45,48].

2.2. Economic and Market Drivers

Through differentiated "lean-green" competitive strategies, companies can drive cost savings and quickly deliver green products to customers to meet market demand.

Cost savings (D_9): Reduce energy and resource consumption, eliminate all work methods that do not add value, and even if the work adds value, the time and resource effort spent does not exceed the minimum threshold [15–51].

Competitive advantage (D_{10}): Maintain a competitive advantage in the market through the concept of greening products, while giving the company a competitive advantage by saving costs, optimizing product quality, and responding quickly to customer needs [15–51].

2.3. Policy Drivers

The lean and green role of companies is driven by government agencies and several other organizations, mostly through required and industry-specific rules and industry barriers, such as, industry certifications, and through internal incentive systems that promote the active promotion and implementation of lean and green-related strategies, systems and plans by all departments and employees.

Government laws and regulations (D_{11}): Government laws and regulations related to environmental protection, pollution control, landfill tax, emission standards, and other measures required by enterprises [15,18,21,35,48].

Professional certified management systems (D_{12}): The adoption, implementation, improvement, and certification of ISO9000 quality management system, ISO14000 environmental management system, OHSAS80000 occupational health and safety management system, and ISO50000 energy management system promote the continuous lean and green direction of the enterprise [49–55].

Incentive mechanism (D_{13}): Government agencies reward and punish managers and companies in the industry in which they operate for carrying out green management [21,23,43–48].

2.4. Consumer and Other Social Stakeholder Drivers

Consumers use their "monetary votes" to drive the lean-green of enterprises through price, responsiveness, and green consumption. By increasing public knowledge, keeping an eye on the government's environmental management responsibilities, and supporting company greening, the public indirectly drives the greening of companies.

Green brand image (D_{14}): The lean-greening of enterprises is driven by the awareness of building a positive brand image through green products, as well as the positive degree of eco-trademark or brand image of products and the degree of customer recognition of the company's green trademark [15,21,29,46,48,51,53].

Public pressure (D_{15}): It includes demands and monitoring from the local community where the company is located, such as partners in the supply chain, shareholders of the company, NGOs, and media [15,18,21,35,48,56,57].

The effect factor indicators of lean-green drivers on the collaborative implementation of lean-green manufacturing systems in manufacturing enterprises have varying degrees of influence. Therefore, the magnitude of influence, i.e., weight, of each influence factor indicator on the lean-green system will directly affect the overall evaluation results, so it is important to choose the weight calculation method reasonably. AHP, which is highly preferred for its simplicity and flexibility, uses a combination of qualitative and quantitative analysis to construct a two-by-two judgment matrix between each influence factor and calculate the initial weight value of each influence factor.

There may be correlative influence relationships among the impact evaluation indicators of lean-green drivers. Assuming that the 15 indicators in the four categories are kept independent of each other, and do not overlap with each other, then it does not mean that there is no interrelated influence relationship among these indicators. For example, at the internal driver level, if top management has sufficient awareness of the company's green competitive advantage, and has made commitments to government agencies and the public, then the degree to which green production combined with lean production and environmental protection are included in the planning will increase, and the company's green management activities will receive sufficient attention and support. Therefore, the awareness and commitment of top management (D_2) will have an impact on other factors, such as lean-green integrated strategic planning and communication (D_3), continuous improvement (D_4), and employee awareness and training (D_1). Other indicators' adoption and the outcomes attained will, in turn, have an impact on top management's knowledge and commitment. The implementation of other indicators and the results achieved will in turn influence the awareness and commitment of top management (D_2), and strengthen the belief and will of top management, forming a virtuous circle that will facilitate the further progress of the company on the road to lean and green. At the same time, there may be

a correlative influence relationship between the driving evaluation indicators belonging to different lean-green driving factors. For example, if there is a substantial demand from end users for quick delivery, high quality, and ecologically friendly products, then it may promote a strong willingness of manufacturing companies to establish a good market image of the brand based on green products through the advantages that can be created by lean production. In addition, on the other hand, it may cause sufficient attention and support for lean-green business management activities within the company, so that the formation of a green brand image (D_{14}) at the level of consumer and other social stakeholder drivers can affect the establishment and maintenance of competitive advantage (D_{10}) at the level of economic and market drivers, etc.

In light of the foregoing, the four categories and 15 evaluation indicators used to reflect the relationship between supply-lean-green drive can be thought of as a complex network with intricate correlated influence relationships between elements. The significance effect that an indicator or factor has by connecting other indicators or factors determines the importance of the indicator in a complex network [58]. The decision laboratory analysis (DEMATEL) method in complex network theory is able to reveal important influencing factors as well as internal constructions by analyzing the logical relationships between factors in the system with the direct influence matrix to calculate the degree of influence, the degree of being influenced, the degree of cause, and centrality of the factor [59]. Therefore, quantitative evaluation based on the DEMATEL method was used to analyze the lean-green drive intensity evaluation index system.

3. Research Methodology

3.1. Fuzzy AHP-DEMATEL Model

AHP calculates the weights based on the relative relevance of the various indicators, which is highly accurate and valid, but it ignores the interdependence of the various indicators. It assumes that each indicator is independent of each other, while the driver indicators of collaborative integrated implementation of lean-green manufacturing system consider more factors and cannot completely guarantee the absolute independence among indicators. The DEMATEL method can solve this problem by determining the weights using the degree of mutual influence between indicators. Therefore, the initial weights of indicators are determined by using the AHP method first, and then the DEMATEL method is adopted to correct the initial weights, reduce the subjective one-sidedness in the process of weight assignment, improve the accuracy and rationality, and make the evaluation results more scientific. Basílio et al. (2022) searched and reviewed papers on the use of multi-criteria decision-making methods between January 1977 and 29 April 2022, including titles, abstracts, keywords, and articles, and found that methods such as AHP and DEMATEL are the most popular multi-criteria decision-making methods [60].

3.1.1. Calculation of Initial Weights Based on Fuzzy AHP

Analytic Hierarchy Process is an effective tool for dealing with complex decision-making problems. It is a strategy for making decisions that breaks down the components that are usually involved in making decisions into levels, such as objectives, criteria, and options; on the basis of which qualitative and quantitative analysis is performed. This method is a hierarchical weighted decision analysis method proposed by Professor Satie of University of Pittsburgh, an American operations researcher, in the early 1970s when he was working for the U.S. Department of Defense on the topic of "power allocation based on the contribution of each industrial sector to national welfare", applying network system theory and multi-objective comprehensive evaluation methods. Analytic hierarchy process is a simple decision-making method for complex decision-making problems with multiple objectives, multiple criteria, or unstructured characteristics, by mathematizing the thinking process of decision-making with less quantitative information, based on an in-depth analysis of the nature of complex decision-making problems, influencing factors and their intrinsic relationships.

The decision problem is divided into several hierarchical structures according to the total objective, each level of sub-objectives, evaluation criteria, etc., using the analytical hierarchy process approach. Then we can use the method of solving the eigenvectors of the judgment matrix to find the priority weight of each element at each level to a certain element of the previous level, and finally the method of weighted sum to the final weight of the total objective. In establishing a hierarchical structure model and constructing a pairwise comparison array by introducing fuzzy set theory to address the limitations of cognitive uncertainty expression under limited information, this study combines the traditional nine-level scale method and triangular fuzzy number for the ratio of the two-two importance degree of each element of the same level regarding a criterion in the previous level in AHP to establish a nine-level scale table, as shown in Table 1.

Table 1. Nine-level fuzzy scale of expert judgment terms.

Scale	Definition	Triangular Fuzzy Number (l_{ij}, m_{ij}, u_{ij})	Countdown (1/u_{ij}, 1/m_{ij}, 1/l_{ij})
1	Equally important	(1,1,1)	(1,1,1)
2	Between equally important and slightly more important	(1,2,3)	(1/3,1/2,1)
3	Slightly more important	(2,3,4)	(1/4,1/3,1/2)
4	Between slightly more important and obviously important	(3,4,5)	(1/5,1/4,1/3)
5	Obviously important	(4,5,6)	(1/6,1/5,1/4)
6	Between obviously important and strongly important	(5,6,7)	(1/7,1/6,1/5)
7	Strongly Important	(6,7,8)	(1/8,1/7,1/6)
8	Between strongly important and extremely important	(7,8,9)	(1/9,1/8,1/7)
9	Extremely important	(8,9,9)	(1/9,1/9,1/8)

According to the characteristics of the problem and the overall aim that is supposed to be attained, the first phase of the analytical hierarchy process model is to list all the contributing aspects of the decision problem. First, to establish an orderly hierarchy according to the interrelationship, mutual influence, and affiliation between the influencing factors, so as to obtain a structural analysis model of multiple levels. Secondly, to reflect the subjective judgment about the importance of each factor in a quantitative way, and on this basis, to compare the factors on the same level with each other and to establish a judgment matrix. In this manuscript, Table 1 is used to collect experts' opinions on the two relative importance of each factor. Assuming that there are 'n' factors in an index layer, and the relative importance of the i-th factor to the j-th factor as determined by the K-th expert, the fuzzy judgment matrix of this index layer is shown in Equation (1).

$$\widetilde{A}^{(K)} = \widetilde{a}_{ij}^{(k)} = \begin{bmatrix} (1,1,1) & (l_{12}^{(k)},m_{12}^{(k)},u_{12}^{(k)}) & \cdots & (l_{1n}^{(k)},m_{1n}^{(k)},u_{1n}^{(k)}) \\ (1/u_{12}^{(k)},1/m_{12}^{(k)},1/l_{12}^{(k)}) & (1,1,1) & \cdots & (l_{2n}^{(k)},m_{2n}^{(k)},u_{2n}^{(k)}) \\ \vdots & \vdots & \ddots & \vdots \\ (1/u_{1n}^{(k)},1/m_{1n}^{(k)},1/l_{1n}^{(k)}) & (1/u_{2n}^{(k)},1/m_{2n}^{(k)},1/l_{2n}^{(k)}) & \cdots & (1,1,1) \end{bmatrix}_{k=1,2,\cdots,K\ i,j=1,2,\cdots,n} \tag{1}$$

For the evaluation of the K-th expert, the triangular fuzzy number of each factor weight is calculated using the modified formula proposed by W.Y et al. [61] as shown in Equation (2).

$$\widetilde{X}_i^{(k)} = \left(\frac{\sum_{j=1}^n l_{ij}^{(k)}}{\sum_{j=1}^n l_{ij}^{(k)} + \sum_{z=1,z\neq i}^n \sum_{j=1}^n u_{zj}^{(k)}}, \frac{\sum_{j=1}^n m_{ij}^{(k)}}{\sum_{z=1}^n \sum_{j=1}^n m_{zj}^{(k)}}, \frac{\sum_{j=1}^n l_{ij}^{(k)}}{\sum_{j=1}^n u_{ij}^{(k)} + \sum_{z=1,z\neq i}^n \sum_{j=1}^n l_{zj}^{(k)}} \right) \tag{2}$$

Equation (2) denotes the triangular fuzzy number of the single ranking weight of the *i*-th factor, determined by the *k*-th expert. By iteratively computing the single ranking weights of each component, it is possible to determine the weight of a compared factor in relation to its upper target layer, and finally the total weight of each factor relative to the target is shown in Equation (3).

$$\widetilde{W}_i^{(k)} = \prod_{m=1}^{n-1} S_i^{(k)(m)}, k = 1, 2, \cdots n \tag{3}$$

In Equation (3), $S_i^{(k)(m)}$ is the weight of the *m*-th layer of indicators, judged by the *k*-th expert, and finally, the weight of the attributes is DE-fuzzified according to the fuzzy mean method, assuming that the triangular fuzzy number of their final weights is $\widetilde{w}_{A_i} = \left(\widetilde{w}_{Ai}^L, \widetilde{w}_{Ai}^M, \widetilde{w}_{Ai}^U \right)$, and the explicit weight value is w_{A_i} obtained by DE-fuzzifying $\widetilde{W}_i^{(k)}$ according to the fuzzy mean method, and the calculation formula is shown in Equation (4).

$$w_{A_i} = \frac{w_{A_i}^L + 2w_{A_i}^M + w_{A_i}^U}{4} \tag{4}$$

In the construction of the judgment matrix $\widetilde{A}^{(K)}$, in order to prevent the phenomenon that "factor A is more important than factor B, factor B is more important than factor C, and factor C is more important than factor A", which does not conform to normal logic, a consistency test is conducted on W. Take the elements of the criterion *F* as an example.

Calculate the maximum characteristic root $\lambda_{\max}$ of the judgment matrix $\widetilde{A}^{(K)}$, as shown in Equation (5), where $(\widetilde{A}^{(K)}W)_i$ denotes the *i*-th component of the vector, as shown in Equation (6).

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(\widetilde{A}^{(K)}W)_i}{W_i} \tag{5}$$

$$\widetilde{A}^{(K)}w = \begin{bmatrix} (1,1,1) & (l_{12}^{(k)}, m_{12}^{(k)}, u_{12}^{(k)}) & \cdots & (l_{1n}^{(k)}, m_{1n}^{(k)}, u_{1n}^{(k)}) \\ (1/u_{12}^{(k)}, 1/m_{12}^{(k)}, 1/l_{12}^{(k)}) & (1,1,1) & \cdots & (l_{2n}^{(k)}, m_{2n}^{(k)}, u_{2n}^{(k)}) \\ \vdots & \vdots & \ddots & \vdots \\ (1/u_{1n}^{(k)}, 1/m_{1n}^{(k)}, 1/l_{1n}^{(k)}) & (1/u_{2n}^{(k)}, 1/m_{2n}^{(k)}, 1/l_{2n}^{(k)}) & \cdots & (1,1,1) \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} \sum_{i=j=1}^{n} a_{1j}w_i \\ \sum_{i=j=1}^{n} a_{2j}w_i \\ \vdots \\ \sum_{i=j=1}^{n} a_{ij}w_i \\ \vdots \\ \sum_{i=j=1}^{n} a_{nj}w_i \end{bmatrix} \tag{6}$$

The fuzzy value of attribute $(\widetilde{A}^{(K)}W)_i$ according to the fuzzy mean method can be DE-fuzzified according to Formula (4), and the Consistency Index *C.I.* of the judgment matrix is calculated, where n indicates the order of the judgment matrix. The calculation formula is determined by Equation (7).

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \tag{7}$$

The judgement matrix's consistency indicator is then determined using the stochastic consistency ratio C.R. The calculation formula is given in Equation (8).

$$C.R. = \frac{C.I.}{R.I.} \tag{8}$$

The average randomness index of the judgement matrix, or *R.I.*, is proposed to assess if the judgement matrix of various orders exhibits adequate consistency. For the random consistency index of the judgment matrix, the *R.I.* values are shown in Table 2.

Table 2. Random consistency index.

n	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54	1.56	1.58	1.59

If C.R. < 0.1, the judgment matrix is considered to have satisfactory consistency, and the relative importance, calculated based on this judgment matrix, is acceptable. If this condition is not satisfied, the judgment matrix needs to be revised again until satisfactory agreement is obtained.

The consistency index of the total ranking of the hierarchy relative to the recursive hierarchy is calculated in Equation (9):

$$CI_G = \sum_{k=1}^{h} \sum_{i=1}^{nk} w_{ik} \times CI_{ik+1} \tag{9}$$

The average random consistency index of the total hierarchical ranking, relative to the total recursive hierarchy, is calculated in Equation (10):

$$RI_G = \sum_{k=1}^{h} \sum_{i=1}^{nk} w_{ik} \times RI_{ik+1} \tag{10}$$

Finally, the total relative consistency index of the recursive hierarchy is calculated, as given in Equation (11):

$$CR_G = \frac{CI_G}{RI_G} \tag{11}$$

Similarly, when CR_G < 0.1, it indicates that the consistency of the overall judgment matrix is acceptable.

3.1.2. Calculation of Centrality Based on Fuzzy DEMATEL

Since the DEMATEL method is based on expert experience for scoring, the results are influenced by individual differences and expert subjectivity. So, combining fuzzy theory and the DEMATEL method can eliminate the problems such as semanticization and fuzzification of expert evaluation information, by converting the expert scoring into the corresponding Triangular Fuzzy Number (TFN) as well to obtain the direct influence matrix, and then fuzzifying it, using the defuzzification method of Opricovic et al. [62] to convert the triangular fuzzy number into an accurate value, by the following steps.

(1)   Firstly, the mapping relationship between linguistic variables and fuzzy is established, as shown in Table 3.

Table 3. Semantic transformation table.

Language Variables	Triangular Fuzzy Number (l_{ij}, m_{ij}, u_{ij})
No effect (NO)	(0,0,1)
Very low impact (VL)	(0,1,2)
Low impact (L)	(1,2,3)
High impact (H)	(2,3,4)
Very high impact (VH)	(3,4,4)

(2)   Conduct research for the relevant personnel and experts of lean-green manufacturing projects in manufacturing enterprises, and $\widetilde{\chi}_{ij}^{(k)}$ is the result of the determination of

the k-th evaluator, thus establishing the direct impact matrix $\widetilde{M}^{(k)} = \left[\widetilde{\chi}_{ij}^{(k)}\right]_{n \times n}$. The initial direct impact matrix is as follows:

$$
\widetilde{M}^{(k)} = \left[\widetilde{\chi}_{ij}^{(k)}\right]_{n \times n} = \begin{bmatrix} (0,0,1) & (l_{12}^{(k)}, m_{12}^{(k)}, u_{12}^{(k)}) & \cdots & (l_{1n}^{(k)}, m_{1n}^{(k)}, u_{1n}^{(k)}) \\ (l_{21}^{(k)}, m_{21}^{(k)}, u_{21}^{(k)}) & (0,0,1) & \cdots & (l_{2n}^{(k)}, m_{2n}^{(k)}, u_{2n}^{(k)}) \\ \vdots & \vdots & \ddots & \vdots \\ (l_{n1}^{(k)}, m_{n1}^{(k)}, u_{n1}^{(k)}) & (l_{n2}^{(k)}, m_{n2}^{(k)}, u_{n2}^{(k)}) & \cdots & (0,0,1) \end{bmatrix} \tag{12}
$$
$$
i,j = 1, 2, \cdots n
$$

(3) Calculate the left and right standard values xls_{ij}^k and xus_{ij}^k.

$$
xls_{ij}^k = \frac{xm_{ij}^k}{1 + xm_{ij}^k - xl_{ij}^k}, \ xus_{ij}^k = \frac{xu_{ij}^k}{1 + xu_{ij}^k - xm_{ij}^k} \tag{13}
$$

(4) Calculate the integrated standardized value x_{ij}^k.

$$
x_{ij}^k = \frac{xls_{ij}^k \times (1 - xls_{ij}^k) + xus_{ij}^k \times xus_{ij}^k}{1 - xls_{ij}^k + xus_{ij}^k} \tag{14}
$$

(5) Calculate the value of the influence of the i-th factor on the j-th factor.

$$
\chi_{ij}^{(k)} = \min_{1 \le k \le n} l_{ij}^k + x_{ij}^k \Delta_{\min}^{\max} \tag{15}
$$

(6) The average direct impact matrix is averaged over the processed direct impact matrix according to $M^{(k)} = \left[\chi_{ij}^{(k)}\right]_{n \times n}$ to obtain the average direct impact matrix $M = \left[\chi_{ij}\right]_{n \times n}$. Then the average direct impact matrix is normalized to calculate the combined impact matrix $M = \left[\chi_{ij}\right]_{m \times n}$.

(7) In order to analyze the indirect influence relationship between the factors, it is necessary to solve the integrated influence matrix M'', I is the unit matrix. This can be found using Equations (16) and (17).

$$
M' = \frac{\chi_{ij}}{\max(\sum_{j=1}^{n} \chi_{ij})} \tag{16}
$$

$$
M'' = M' + M'^2 + \cdots + M'^n = \frac{M'(I - M'^n)}{(I - M')} = M'(I - M')^{-1} \tag{17}
$$

(8) Calculate the cause degree ($R_i - C_i$) and the center degree ($R_i + C_i$) of the driving strength between the lean-green drivers.

The degree of influence and the degree of being influenced of each factor indicator can be determined from the integrated influence matrix as Ri and Ci, respectively (see Equation (18), and then the centrality $m_i = R + C$, which is used to indicate the magnitude (importance) of the role of each factor in all evaluation indicators, and the cause $r_i = R - C$, which is used to indicate the internal construct can be deduced.

$$
R_i = \sum_{j=1}^{n} t_{ij} \quad C_j = \sum_{i=1}^{n} t_{ij} \tag{18}
$$

3.1.3. Comprehensive Weight Calculation Based on Fuzzy AHP-DEMATEL

The degree of mutual influence between components and the relationship between criteria or elements can both be successfully determined by DEMATE. However, the DEMATEL method does not take into account the high or low weights among the evaluation indicators. The AHP method is different from the DEMATEL method in the aspect that the AHP method determines the weights by two-by-two comparison among the influencing factors. However, the premise of determining the weights is that each influencing factor is independent of the others. While the lean-green manufacturing system involves a wide range of aspects, it is difficult to ensure the independence of each influencing factor, and if only the AHP may cause bias in the results. When it comes to the DEMATEL method, it obtains the comprehensive weights by calculating the initial weights, influence degree, and influenced degree, and integrating the influenced degree into the influence weights. Therefore, the advantages of both these methods are combined resulting in AHP-DEMATEL, and the combined weights of factor '*i*' are constructed based on the results of AHP and DEMATEL analysis. It is calculated in Equation (19).

$$z_i = \frac{w_i \times m_i}{\sum_{i=1}^{n} w_i \times m_i}, \quad i = 1, 2, \cdots n \tag{19}$$

where, w_i is the weight of each influencing factor calculated by the AHP method, and m_i is the centrality of each influencing factor calculated by the AHP method.

3.2. DEMATEL-ISM Model

ISM model is based on graph theory, and it is an effective network analysis tool to analyze and deal with the structure of complex systems with the help of logical matrix operations. ISM develops multi-layer recursive structural models by breaking down complex systems with the aid of computer assistance and human empirical expertise. Based on this, DEMATEL and ISM can be used together to create the hierarchical structure of the indicator system in addition to identifying its major components and level of influence. The specific steps of the DEMATEL-ISM model are as follows:

(1) Based on the final integrated impact matrix M'' obtained in the DEMATEL method in Section 3.1, the unit matrix is introduced into the overall impact matrix D, as shown in Equation (20).

$$D = I + M'' = \left[d_{ij} \right]_{n \times n} \tag{20}$$

(2) Set the threshold value λ, and calculate the reachability matrix H. Based on the experience as well as the extrapolation of the threshold value, it can be calculated by Equation (21).

$$\lambda = \mu + \delta \tag{21}$$

where, μ and δ are the mean and standard deviation of all elements in the overall impact matrix M'', respectively. Equation (22) determines the elements in the final reachable matrix.

$$h_{ij} = \begin{cases} 0, d_{ij} \prec \lambda \\ 1, d_{ij} \succ \lambda \end{cases} \quad (i = 1, 2, \cdots, n; j = 1, 2, \cdots, n) \tag{22}$$

(3) Calculate the reachable set, current set, and common set of the overall impact matrix H. The elements in the final reachable matrix are hierarchically divided to build the ISM model.

4. Case Study

4.1. Calculation of Initial Weights Based on Fuzzy AHP

In order to analyze the relationship between the drivers of lean-green manufacturing system in a manufacturing company S, the S company invited senior scholars, experts,

senior management of lean-green manufacturing system, and senior management consultants to form an evaluation expert group according to the evaluation criteria in Table 1. The evaluation team was composed of many experts and scholars from manufacturing enterprises, including senior management of lean-green manufacturing system and senior management consultants, who used the questionnaire survey method to score each influence factor according to its relative importance on a scale of 1–9, and established a judgment matrix. A total of 70 questionnaires were distributed in this study, and 65 questionnaires were received. The information about the questionnaire participant population is shown in Table 4. Taking the judgment results of D_{11}–D_{13} indicators under policy-driven conditions as an example for calculation, the judgment results of expert 1 is shown in Table 5.

Table 4. Distribution of experts participating in the questionnaire.

Category		Distribution of Questionnaires		Valid Questionnaires Collected	
		Number	Percentage	Number	Percentage
Gender	Man	65	92.86%	60	92.31%
	Woman	5	7.14%	5	7.69%
Company size	Small enterprises	30	42.86%	28	43.08%
	Medium-sized enterprises	25	35.71%	24	36.92%
	Large enterprises	15	21.43%	13	20.00%
Seniority	5 years and below	10	14.29%	10	15.38%
	6–10 years	10	14.29%	10	15.38%
	11–15 years	30	42.86%	27	41.54%
	16 years and above	20	28.57%	18	27.69%
Degree	undergraduate	35	50.00%	32	49.23%
	Master	30	42.86%	28	43.08%
	Doctor	5	7.14%	5	7.69%
Lean-Green Management Levels	Senior	20	28.57%	19	29.23%
	Medium	30	42.86%	29	44.62%
	Junior	20	28.57%	17	26.15%
Level of digitization	Senior	10	14.29%	10	15.38%
	Medium	40	57.14%	36	55.38%
	Junior	20	28.57%	19	29.23%

Table 5. Opinions on the importance of each indicator factor under policy-driven conditions two-by-two judgment.

Experts	C_1	D_{11}	D_{12}	D_{13}
	D_{11}	(1,1,1)	(7,8,9)	(1,2,3)
Expert 1	D_{12}	(1/9,1/8,1/7)	(1,1,1)	(1/4,1/3, 1/2)
	D_{13}	(1/3,1/2,1)	(2,3,4)	(1,1,1)

Based on Table 4, construct the fuzzy judgment matrix for this hierarchy.

$$\widetilde{A}_{C_3}^{(1)} = \begin{bmatrix} (1,1,1) & (7,8,9) & (1,2,3) \\ (1/9,1/8,1/7) & (1,1,1) & (1/4,1/3,\ 1/2) \\ (1/3,1/2,1) & (2,3,4) & (1,1,1) \end{bmatrix}$$

The fuzzy judgment matrix $\widetilde{A}_{C_3}^{(1)}$ is calculated using Equation (2) to obtain the triangular fuzzy number of the weight vector of each indicator factor under the policy-driven condition.

$$\widetilde{S}_{C_3}^{(1)} = \left\{ \begin{matrix} \widetilde{S}_{D_{11}}^{(1)} \\ \widetilde{S}_{D_{12}}^{(1)} \\ \widetilde{S}_{D_{13}}^{(1)} \end{matrix} \right\} = \begin{bmatrix} (0.5408, 0.6486, 0.7347) \\ (0.0668, 0.0860, 0.1175) \\ (0.1854, 0.2654, 0.3667) \end{bmatrix}$$

The matrix $\widetilde{A}_{C_3}^{(1)}$ is also tested for consistency at the same time. In addition, after the Formula (4) and defuzzification, we obtain from the Formulas (7) and (8): $\lambda_{\max}$ = 3.0092, Ri = O.58, *C.I.* = 0.0046, C.R. = 0.0079 < 0.10, and the judgment matrix satisfies the consistency. Similarly, according to Equations (9) and (10), the consistency index C.R. = 0.0921 < 0.10 of the total ranking of the hierarchy relative to the recursive hierarchy, the comprehensive ranking satisfies the consistency test, and the weights of each index are reasonably assigned.

Formula (3) was used to determine the triangle fuzzy values of each index's weights, and the mean values of each expert's determination findings were obtained. Formula (4) then was used to carry out the fuzzification procedure, and the results are shown in Table 6.

Table 6. Defuzzified values of the initial weights of the drivers.

Driving Factors	Initial Weights	Driving Factors	Initial Weights	Driving Factors	Initial Weights
D_1	0.0415	D_6	0.0685	D_{11}	0.0536
D_2	0.0962	D_7	0.0538	D_{12}	0.0282
D_3	0.0223	D_8	0.0361	D_{13}	0.0415
D_4	0.0586	D_9	0.1564	D_{14}	0.0596
D_5	0.0826	D_{10}	0.1696	D_{15}	0.0315

4.2. Calculation of Index Weights Based on Fuzzy DEMATEL

According to Table 2, the experts in Section 4.1 are invited to give their judgment on the degree of mutual influence of each index. The judgment result of expert 1, according to Equation (5) direct influence matrix $\widetilde{M}^{(1)} = \left[\widetilde{\chi}_{ij}^{(1)}\right]_{15\times15}$, is shown below:

$$\widetilde{M}^{(1)} = \begin{bmatrix} (0,0,1) & (0,0,1) & \cdots & (0,0,1) \\ (2,3,4) & (0,0,1) & \cdots & (0,0,1) \\ \vdots & \vdots & \ddots & \vdots \\ (0,0,1) & (2,3,4) & \cdots & (0,0,1) \end{bmatrix}_{15\times15}$$

Combining the opinions of other experts, the direct influence matrix after defuzzification was obtained using Equations (13)–(15), and the mean values were taken for all experts, as shown in Table 7.

Table 7. Lean Green Driver Indicator Composite Impact Matrix.

	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}	D_{15}
D_1	0.015	0.003	0.003	0.154	0.018	0.009	0.141	0.113	0.165	0.146	0.001	0.019	0.001	0.062	0.007
D_2	0.171	0.013	0.135	0.206	0.170	0.152	0.200	0.171	0.152	0.177	0.002	0.131	0.002	0.169	0.020
D_3	0.059	0.007	0.007	0.131	0.101	0.055	0.077	0.081	0.089	0.105	0.001	0.063	0.001	0.087	0.010
D_4	0.017	0.007	0.007	0.036	0.055	0.050	0.061	0.071	0.148	0.170	0.001	0.055	0.001	0.133	0.016
D_5	0.028	0.009	0.010	0.173	0.031	0.021	0.154	0.125	0.096	0.153	0.001	0.103	0.001	0.065	0.008
D_6	0.090	0.005	0.006	0.147	0.015	0.013	0.026	0.027	0.157	0.176	0.001	0.051	0.001	0.059	0.007
D_7	0.093	0.007	0.007	0.162	0.027	0.015	0.039	0.156	0.167	0.188	0.001	0.059	0.001	0.110	0.013
D_8	0.018	0.006	0.007	0.120	0.097	0.014	0.108	0.040	0.080	0.095	0.001	0.061	0.001	0.083	0.010
D_9	0.001	0.003	0.003	0.004	0.002	0.002	0.002	0.013	0.002	0.124	0.001	0.003	0.001	0.138	0.017
D_{10}	0.001	0.002	0.002	0.003	0.002	0.002	0.002	0.012	0.002	0.003	0.001	0.002	0.001	0.123	0.015
D_{11}	0.080	0.123	0.138	0.106	0.037	0.149	0.044	0.041	0.060	0.068	0.000	0.032	0.000	0.046	0.005
D_{12}	0.166	0.087	0.098	0.233	0.167	0.151	0.161	0.165	0.148	0.210	0.002	0.054	0.002	0.172	0.021
D_{13}	0.050	0.125	0.100	0.202	0.044	0.153	0.170	0.100	0.165	0.107	0.001	0.043	0.001	0.078	0.009
D_{14}	0.008	0.019	0.021	0.026	0.015	0.014	0.017	0.096	0.015	0.027	0.010	0.019	0.010	0.026	0.123
D_{15}	0.057	0.152	0.167	0.138	0.060	0.105	0.073	0.109	0.076	0.165	0.082	0.122	0.082	0.157	0.019

Finally, ranking analysis was carried out based on the centrality pairs of each factor index, and the influence degree, influenced degree, cause degree, and centrality of each

factor were determined using the conventional DEMATEL approach, and the results are shown in Table 8.

Table 8. Influence, Influenced, Cause and Centrality of lean-green driving factors.

Driving Factors	Influence	Influenced	Cause	Centrality	Sort
Continuous Improvement (D_4)	0.830	1.840	−1.010	2.669	1
Professional certified management systems (D_{12})	1.838	0.819	1.019	2.657	2
Senior management awareness and commitment (D_2)	1.872	0.567	1.305	2.438	3
Total employee participation and employee empowerment (D_7)	1.047	1.277	−0.230	2.324	4
Competitive advantage (D_{10})	0.174	1.915	−1.741	2.088	5
Organizational Culture (D_8)	0.739	1.318	-0.579	2.058	6
Green brand image (D_{14})	0.447	1.507	−1.060	1.953	7
Public pressure (D_{15})	1.562	0.301	1.261	1.863	8
Cost savings (D_9)	0.314	1.524	−1.209	1.838	9
Business Process Reengineering and Change (D_5)	0.978	0.842	0.136	1.820	10
Employee awareness and training (D_1)	0.856	0.853	0.003	1.709	11
Technology Upgrade (D_6)	0.780	0.905	−0.125	1.685	12
Integrated strategic planning and communication (D_3)	0.872	0.710	0.162	1.583	13
Incentive mechanism (D_{13})	1.348	0.104	1.244	1.452	14
Government laws and regulations (D_{11})	0.930	0.104	0.826	1.034	15

The difference between the row and column sums is because of the degree of the factor, as shown in Figure 2, which represents the cause degree of each factor indicator. The sum of row and column is called the centrality of the factor, and Figure 3 shows the centrality of each factor.
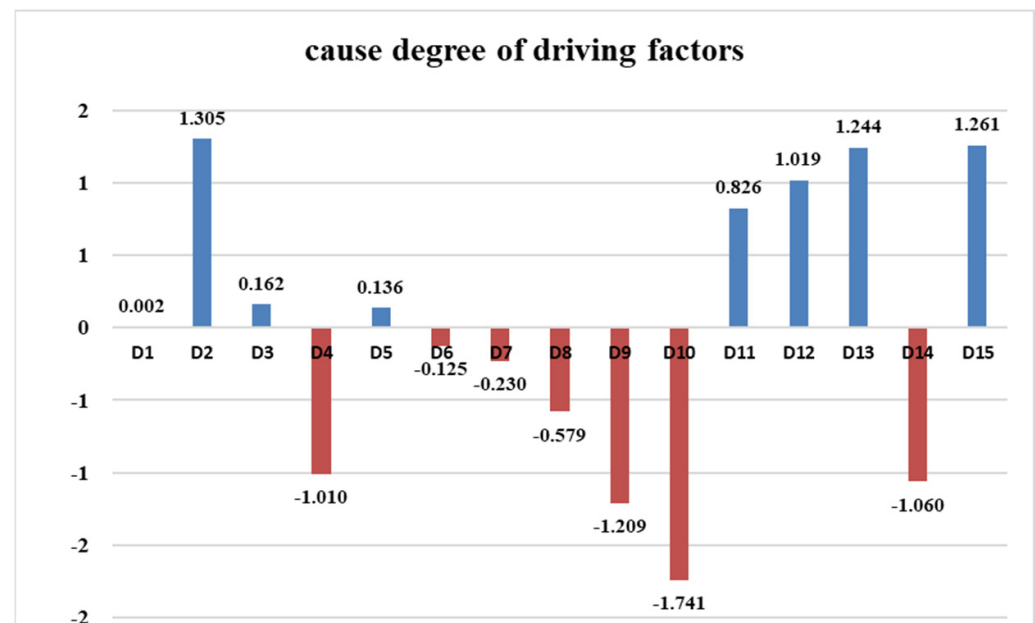

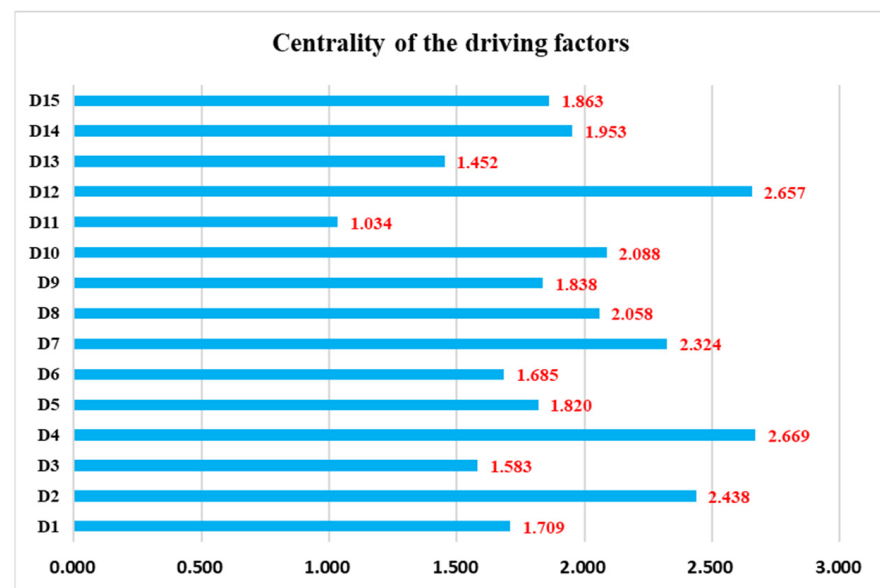**Figure 2.** Distribution of cause degree of driving factors.

Figure 3. Centrality distribution of driving factors.

4.3. Comprehensive Weight Calculation Based on Fuzzy AHP-DEMATEL

The initial weights and centrality of the risk factors are integrated according to Equation (15), such that the integrated weight values are obtained and ranked. The results are shown in Table 9. A comparison of the initial weights and combined weights of the lean green integration driver factors for manufacturing companies as can be seen below in Figure 4.

Table 9. Combined weights of driving factors.

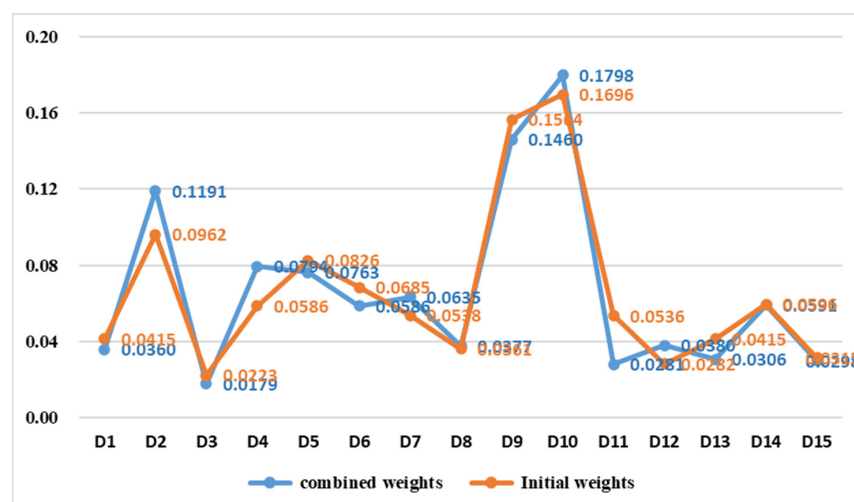| Factors	Combined Weights	Sort	Factors	Combined Weights	Sort	Factors	Combined Weights	Sort
D_1	0.0360	11	D_6	0.0586	8	D_{11}	0.0281	14
D_2	0.1191	3	D_7	0.0635	6	D_{12}	0.0380	9
D_3	0.0179	15	D_8	0.0377	10	D_{13}	0.0306	12
D_4	0.0794	4	D_9	0.1460	2	D_{14}	0.0591	7
D_5	0.0763	5	D_{10}	0.1798	1	D_{15}	0.0298	12

Figure 4. Initial, combined weights of driving factors.

4.4. Analysis Process Based on the DEMATEL-ISM Method

Using MATLAB software, the overall impact matrix D is first calculated according to Equation (20), and then the mean μ, and standard deviation δ of all elements in the matrix M'' are found with the following threshold values.

$$\mu = 0.0648 \; \delta = 0.0531 \; \lambda = \mu + \delta = 0.1179$$

Execute Equation (22) to calculate the reachable matrix H, as shown in Table 10.

Table 10. Reachable matrix of driving factors.

	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}	D_{15}
D_1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0
D_2	1	0	1	1	1	1	1	1	1	1	0	1	0	1	0
D_3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D_4	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0
D_5	0	0	0	1	0	0	1	1	0	1	0	0	0	0	0
D_6	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0
D_7	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0
D_8	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D_9	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
D_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
D_{11}	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
D_{12}	1	0	0	1	1	1	1	1	1	1	0	0	0	1	0
D_{13}	0	1	0	1	0	1	1	0	1	0	0	0	0	0	0
D_{14}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
D_{15}	0	1	1	1	0	0	0	0	0	1	0	1	0	1	0

All rows and columns of the reachable matrix are summed up separately, and then sorted from largest to smallest according to rows, and then sorted from largest to smallest according to columns. This sorting is performed to obtain the reconstructed reachable matrix. The influencing factors with the same serial numbers are divided into uniform orders, and the hierarchical structure diagram of each factor index is obtained, and the hierarchical structure diagram shown in Figure 5 is constructed.
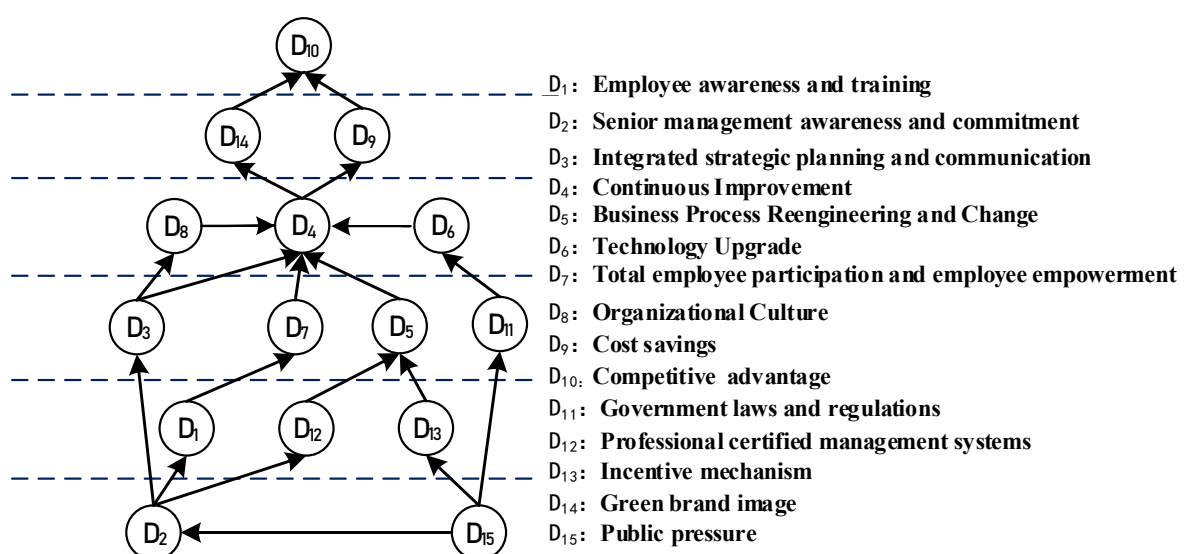

D_1: **Employee awareness and training**
D_2: **Senior management awareness and commitment**
D_3: **Integrated strategic planning and communication**
D_4: **Continuous Improvement**
D_5: **Business Process Reengineering and Change**
D_6: **Technology Upgrade**
D_7: **Total employee participation and employee empowerment**
D_8: **Organizational Culture**
D_9: **Cost savings**
D_{10}: **Competitive advantage**
D_{11}: **Government laws and regulations**
D_{12}: **Professional certified management systems**
D_{13}: **Incentive mechanism**
D_{14}: **Green brand image**
D_{15}: **Public pressure**

Figure 5. Hierarchy of indicators of driving factors.

5. Results, Discussion, and Implications

5.1. Degree of Influence and Degree of Influenced Analysis

Through the comprehensive influence matrix analysis, it can be concluded from Table 8 that the causal factors (factors with causality degree greater than zero) affecting Lean-green implementation are, in descending order of importance, top management awareness and commitment (D_2), public pressure (D_{15}), incentives (D_{13}), professional certification management system (D_{12}), laws and regulations set by the government (D_{11}), integrated strategic planning and communication (D_3), Business Process Reengineering and Change (D_5), and Employee Awareness and Training (D_1).

As can be seen from Figure 2, the awareness and commitment of top management (D_2) has the greatest degree of cause. Therefore, the top management of manufacturing companies must be aware of and committed to making decisions regarding the introduction of lean-green advanced manufacturing models in their organizations if the analysis of the drivers of lean-green implementation in manufacturing companies is to be successful. It can be used to provide continuous attention and resources to support them during the implementation promotion process, and to establish a process change and organizational corporate culture for companies to adapt to Lean-green. This also indicates whether the implementation of a lean-green manufacturing system is valued by the company. The company can be guaranteed to support the lean-green manufacturing system if top management values and supports it in this area and provides adequate financial, human, and policy assistance. Next, public pressure (D_{15}), incentives (D_{13}), professional certification management system (D_{12}), government laws and regulations (D_{11}), and integrated strategic planning and communication (D_3) are also key drivers. The key factors of public pressure (D_{15}), incentive mechanism (D_{13}), and laws and regulations set by the government (D_{11}) are also the external facilitators of external pressure on companies to respond to external voices of government, society, and informal organizations in order to better expand market share and build green brands and competitive advantages. The professional certification management system (D_{12}), and integrated strategic planning and communication (D_3) are the internal pressure and action guide and direction for the implementation of lean-green manufacturing system within the company. To adopt internal lean-green measures to accomplish the integration of economic, environmental, and social benefits, the top management set a lean-green strategy as well as certification requirements for each individual management system.

The outcome factors (factors with less than zero cause) are, in descending order of importance: competitive advantage (D_{10}), cost savings (D_9), green brand image (D_{14}), continuous improvement (D_4), organizational culture (D_8), full participation and employee empowerment (D_7), and technology upgrades (D_6). The outcome factor is the influence of other factors on the implementation of lean-green. So, the root cause can be traced to identify the most primitive influencing factors, so as to realize the smooth, convenient, and profitable implementation of lean-green in the enterprise from the root.

5.2. Centrality and Comprehensive Weighting Analysis

From Table 8, we can conclude that the importance of centrality in descending order is continuous improvement (D_4), professional certification management system (D_{12}), top management awareness and commitment (D_2), full participation and employee empowerment (D_7), competitive advantage (D_{10}), organizational culture (D_8), green brand image (D_{14}), public pressure (D_{15}), cost saving (D_9), business process Re-engineering and Change (D_5), Employee Awareness and Training (D_1), Technology Renewal and Upgrading (D_6), Integrated Strategic Planning and Communication (D_3), Incentives (D_{13}), and Laws and Regulations Established by the Government (D_{11}).

Table 9 and Figure 4 show the initial weights and centrality of each factor indicator considering the interaction between the internal factors to obtain the combined weight and ranking. It can be seen that competitive advantage (D_{10}) has the largest weight value of 0.1798, followed by cost savings (D_9) and top management awareness and commitment

(D_2) with 0.146 and 0.1191, respectively. Continuous improvement (D_4) also has a large influence, with a weight of 0.08 or more. After considering the correlation, the weight of business process reengineering and change (D_5) increases, and the weight of professional certification management system (D_{12}) and full participation and employee empowerment (D_7) decreases. Manufacturing businesses operate in a competitive environment, and the market- and economy's external drivers serve as the initial impetus for implementing various management operation models. Following this, the businesses make internal adjustments to strengthen their competitive position and satisfy external customers' needs and desires while achieving sustainable business practices.

5.3. Analysis of ISM Results

As can be seen in Figure 5, the 15 factor indicators are divided into 6 levels, with a clear hierarchy of each influencing factor indicator. The uppermost factor indicators are the direct causes that result in the integration of collaborative lean-green manufacturing systems, and the middle factor indicators are the indirect causes that drive the integrated collaborative lean-green system implementation. The closer to the bottom level indicates that the driving factors are more fundamental. The drivers are more fundamental the closer we get to the bottom. When motivating the contributing drivers, it is important to improve from the fundamental factors to the direct factors, and to change and motivate the intermediate factors to facilitate the positive cycle of lean-green manufacturing system integration and collaboration.

Therefore, the following points are primarily focused on in order to determine whether the implementation of a lean-green manufacturing system in manufacturing enterprises can be successful and obtain the necessary economic, environmental, and social benefits: (1) Continuous improvement in internal processes, the elimination of all consumption, the conservation of raw materials and energy, among other things, are necessary for the adoption of lean-green in manufacturing enterprises to be successful. This is also used to reduce costs, improve quality, and increase efficiency while achieving more green products. (2) Manufacturing enterprises to implement lean-green measures within the enterprise, should introduce ISO9000 quality management system, ISO14000 environmental management system, OHSAS80000 occupational health and safety management system, and ISO50000 energy management system as far as possible. The implementation and use of these management systems may unintentionally or intentionally give the impression that the business is going green. (3) The support of top management plays a very important role in the introduction and implementation of lean and green management models. The establishment of a lean and green organizational culture can be a champion and a model, thus promoting sustainable development. (4) For government agencies, to give full play to the incentive-driven role of government agencies, the focus of policy incentives should be on managers.

5.4. Conclusions

From the perspective of stakeholders, this paper studies the driving factors of collaborative Integration implementation of lean-green manufacturing system in the context of Industry 4.0. Through literature analysis, the lean-green manufacturing integrated and collaborative implementation drivers are identified as being composed of endogenous and exogenous factors that come together to drive a manufacturing company towards sustainability. The 15 factor indicators identified are derived from published research papers and other results, and their scientific validity and effectiveness have been widely accepted by experts and scholars as the drivers for the integrated and collaborative implementation of lean-green manufacturing systems in Chinese manufacturing companies. The 15 drivers include endogenous lean green drivers including managers and internal staff, and exogenous drivers including shareholders, upstream and downstream companies, consumers, competitors, the public and government agencies, which are divided into four levels of evaluation indicators.

In order to identify the most critical drivers, the relationships between indicators and the structure of the indicator system are analyzed using fuzzy AHP-DEMATEL-ISM, the hierarchy of the complex network constituted by the indicator system is divided, the importance of the indicators is analyzed from a global perspective of the network, and the important factors and major factors influencing the driving lean green system are analyzed. The factors at the bottom of the hierarchy are the awareness and commitment of top management (D_2) and public pressure (D_{15}). The factors at the bottom of the hierarchy influence the other hierarchies through direct and indirect transmission, and are the essential causes of the integrated implementation of lean-green manufacturing systems in Chinese manufacturing enterprises. This is influenced by employee awareness and training (D_1), integrated strategic planning and communication (D_3), government regulations (D_{11}), professional certification management systems (D_{12}) and incentives (D_{13}). The two middle layers are the deep causal layers, which are based on continuous improvement (D_4) and have a complex relationship between other factors and this base, so that if there is a change, it can be passed on quickly, triggering a series of changes and linking to the transitional causal factors at the higher levels through the base factors, thus achieving a coupling of endogenous and exogenous factors. Green brand image (D_{14}) and cost savings (D_9) are transitional drivers, influenced by numerous other indirect factors, necessary for deeper drivers to act on top-level factors, potential influencers of system drivers that cannot be ignored, and the basis for top-level direct drivers. The top-level factor indicator Competitive Advantage (D_{10}) is the direct inducement driver for manufacturing companies to implement a lean-green manufacturing system, the proximate causal factor, and the factor with the largest combined weighting, and the key to achieving sustainable business.

The causal relationships of the 15 driver indicators for the integrated implementation of lean-green manufacturing systems in Chinese manufacturing companies can be explained and illustrated by the explanatory structural progressive order model diagram in Figure 5. The driver indicator system can be divided into six tiers, the structure of which is related to the characteristics of the factors. The drivers are located in the lower two tiers of the hierarchy and are the deeper causal factors of the driver indicator system, driving the other factors. The indicators with high correlation to other factors are located in the middle level of the skeleton diagram, they come out to be closely related to each other, and also carry on the top and bottom to link the factors indicators to form an interlinked system. Top-level factors largely influence the key to the implementation of lean-green manufacturing systems in manufacturing companies, directly affecting the drive, firmness, and sustainability of the driving system from economic, social and environmental aspects.

5.5. Managerial Implications

In conclusion, the cornerstone and secret to sustainable business in a worldwide economy is for manufacturing enterprises to generate a green brand image and their own distinct competitive advantage. However, the integrated and collaborative implementation of a lean-green manufacturing system within a manufacturing company is the result of a combination of external stakeholders, such as internal and external consumers and government, especially external public pressure (consumers) that further drives the determination and will of managers within the company. The fuzzy AHP-DEMATEL-ISM analysis method is constructed to explore the internal linkage of the drivers of integrated and collaborative implementation of lean-green system and to clearly obtain the weights, hierarchy, and influence paths where the key factors are located. This allows for a thorough and scientific analysis of the drivers of integrated and collaborative implementation of lean-green manufacturing systems. This method provides a new analysis idea for the causal analysis of similar responsible system events. Although the method still has some subjectivity, but it is still an effective method for analyzing the drivers of integrated collaborative implementation of lean-green manufacturing systems. For example, in order to describe the relationship between the factors as non-independent and correlated at a later stage in the

research process, the ANP method can be used instead of the AHP method. Moreover, in order to classify the system of driving indicators, the Cluster Analysis method can be used to manage the classification. There are input class indicators and output class indicators in the driving indicators, which can be analyzed using Data Envelopment Analysis in order to the relative validity of a particular unit. Moreover, in order to rank the indicator system, TOPSIS or VIKOR methods can be used. These multi-criteria decision tools can be used individually or in combination. The combined use of these methods allows for more scientific, verifiable, and robust research results.

However, this research project can also identify the root causes that drive the synergistic implementation of lean-green manufacturing system integration from other methods, which will lead to better solutions. In addition, more research is required to complete and further validate the elements that drive the synergistic deployment of lean-green manufacturing systems as this project is still at the preliminary level of quantitative research. Further validation is also needed for different industrial environments, such as process industries, and especially across industries, such as service industries. Moreover, the analytical approach will be extended to other areas, such as improving energy efficiency and reducing water consumption. More research is therefore needed to show that the metrics system driving the integrated and collaborative implementation of lean-green manufacturing systems can be applied across the entire product lifecycle and across all economic activities. In the future, similar studies can be conducted in other developing economies, such as Southeast Asia and India. The structural equation modeling approach can be used to validate the results. In addition, a nonlinear approach with artificial neural networks can also be used. In order to effectively adopt lean-green systems under smart manufacturing in manufacturing companies in China, research on people and other corresponding role factors is needed.

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