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Research on Key Success Factors of Building Sensor-based MES System in Intelligent Manufacturing Environment

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Abstract. The global manufacturing sector urgently needs digital transformation, yet a significant number of enterprises, especially small and medium-sized ones, remain trapped in traditional production models. Data collection largely relies on manual operations and paper-based records, leading to inefficiencies across procurement, production, and warehousing. Production staff depend on manual statistics and daily data compilation, resulting in substantial productivity losses. To address this challenge, this study investigates the key success factors for transitioning to sensor-based Manufacturing Execution Systems (MES) to enable smart manufacturing. Methodologically, a mixed approach is adopted, including questionnaire design and SPSS-based data analysis, incorporating reliability and statistical analyses to validate research hypotheses. Findings indicate that sensor-based MES significantly improves data collection efficiency and reduces response times, offering a viable transformation pathway for traditional manufacturers. Beyond technological feasibility, the study highlights broader implications: supporting national smart manufacturing strategies, bridging the digital divide between developed and developing economies, and proposing policy measures such as sensor subsidies to promote industry-wide adoption. The research underscores the transformative potential of sensor-based MES in driving economic growth, creating employment opportunities, and advancing environmental sustainability, marking a pivotal direction for the future of manufacturing.

Keywords: sensors, Manufacturing Execution System (MES), smart manufacturing, key success factors, manufacturing industries

1 Introduction

In recent years, Manufacturing Execution Systems (MES) have been the focus of industry and academia. As a critical link between corporate strategic planning and operational production, its importance has grown significantly. A. Z. C. Bawono and K. Komarudin [1] argue that the Manufacturing Execution System (MES) is a real-time, shop floor-oriented management system capable of reducing waste in manufacturing processes, thereby shortening cycle times, enhancing product quality, and ultimately enabling the successful implementation of mass customization production systems. S. Mantravadi et al. [2] have proposed that manufacturing faces challenges in integrating information technology (IT) with operational technology (OT) and implementing Industrial Internet of Things (IIoT) solutions to enhance manufacturing flexibility.

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V. M. Tabim et al. [3] propose that Manufacturing Execution Systems (MES) have been considered the 'entrance door' to the Industry 4.0 journey. As part of this journey, this system must operate in real-time and be integrated with several other systems, resulting in modular adaptation and customized implementation of this solution. This increased complexity underscores the importance of the relationship between companies and their technology providers, requiring intensive knowledge-sharing (KS) activities between the parties.

D. J. Ahn et al. [4] argue that, with the advancement of Industry 4.0, Manufacturing Execution Systems (MES) have become a critical component in realizing smart factories. The authors propose a maturity model (MM) accompanied by a corresponding set of indicators to quantify the development level of MES within enterprises, specifically measuring the degree of automation in manufacturing operations and production management processes.

The core of smart manufacturing lies in the Manufacturing Execution System (MES), which serves as the operational backbone for real-time production monitoring and decision-making. While MES adoption is recognized as a critical enabler of Industry 4.0, research gaps persist regarding its integration with Enterprise Resource Planning (ERP) systems and its application in specialized manufacturing sectors. R. Manimegalai et al. [5] point out that manufacturing automation in Industry 4.0 centers on the intelligent control of large-scale manufacturing equipment, with the primary objective of enhancing production efficiency and reducing manufacturing cycle time by minimizing human intervention, while leveraging the Manufacturing Execution System (MES) to achieve end-to-end digital tracking of all transactions—from quotation and order placement to production, quality inspection, and final product shipment.

This study addresses these gaps by investigating how ERP-MES integration can streamline manufacturing processes, eliminate non-value-added activities, and enhance production efficiency in surface treatment plants. Specifically, it aims to: (1) Identify critical success factors for MES implementation in manufacturing; (2) Determine key success factors for MES-driven smart manufacturing construction in this sector. The research focuses exclusively on manufacturing industry， acknowledging limitations such as reliance on secondary data sources, potential respondent subjectivity in survey data, and confidentiality concerns. By focusing on this underserved industry segment, the study contributes to both academic knowledge and practical industrial applications, offering insights that can inform policy and practice for broader manufacturing digitalization, thereby enhancing industry competitiveness and sustainability.

2 Related Work

2.1 Sensors-based Manufacturing Execution System

The MES system integration model layer demonstrates that ERP systems consolidate financial resources to optimize operations. Sensor-based MES systems streamline production workflows and boost efficiency. As an advanced process, PCS significantly enhances product quality:

ERP: With financial analysis and decision-making as the core, optimize the operation of all resources skill.

Sensors-based MES: With the goal of comprehensive production indicators, to achieve product process control with sensors, operation and management technology optimization.

PCS: The full name is Process Control System, which is based on product quality and process. Advanced control technology aimed at art needs.

V. V. Makarov et al. [6] examined the role and positioning of Manufacturing Execution Systems (MES) in digital production, delineated the categories and key features of 'future factories,' demonstrated the digital platform capabilities for the automotive industry, and underscored the imperative of transforming business processes through integrated Cyber-Physical Systems (CPS).

2.2 Sensors-based MES System Core Function Modules

1. Factory resources and status: Production resources consist of personnel, machinery, and equipment. The sensor-based MES system tracks management tools, materials, and manufacturing processes throughout the entire supply chain. Through real-time feedback mechanisms, it dynamically optimizes resource allocation to ensure precise achievement of production targets.

2. Production operation management: Sensors-based MES effectively manages and controls the orders owned

by the enterprise according to the production sequence. The production process generated in the order, production batch and work order. In the event of an emergency or heavy work at the job site. In this case, scheduling adjustments can be made immediately to existing procedures.

3. Production scheduling management: Provide basis priority, attributes, features, and procedures to sequence jobs, and manage equipment loads under parallel or overlapping operations to achieve minimal setup time.

4. Document management: Provide control records and forms required for smooth production line operation. Plan and build as much as possible, including work instructions orders, formulas, drawing numbers and standard operating procedures, engineering notes on changes and instructions on shifts. Resource management and assignments, maintaining records, abilities, qualifications of all employees. Attendance certification tracking, which can analyze employee productivity and resource allocation capability to maximize resources to reassign staff.

5. Process information collection: Can provide production data, usually in the production process and production line. The products produced above will set specific production parameters and be used for records of those product units, data can be retrieved from the production line collection, whether the device is manual or automatic.

6. Personnel management Provide management and control and allocate resources and maintain all staff up-to-date records, staff load, attendance reporting and tracking prove and analyze the productivity and capacity of allocated resources. To redistribute personnel to achieve maximum output.

7. Quality management: Real-time analysis of products collected from production line measurements to ensure product quality control. This feature can also be used during manufacturing detect and define anomalies. Can provide corrections for abnormal causes. Proposals for corrective measures. Quality management includes on-site quality management control and quality assurance obtained from the analysis of the inspection information system card.

8. Process Management: The sensor-based MES system monitors production activities in real time, automatically optimizing processes or providing operators with corrective information. Through equipment monitoring and process control, it captures real-time field alarm data to help managers pinpoint issues or make decisions via process control mechanisms.

9. Maintenance management: This function masters the scheduling of equipment and tools, preventive and corrective measures. Proper maintenance can ensure that equipment and tools are availability. It tracks the functionality of equipment and tools and also maintains a digitized log file of previous issues, when issues when it occurs, diagnosis and correction can be taken directly.

10. Product Lot Tracking: This feature provides maximum visibility of product flow process, which can track the equipment, tools and materials used in real time. What products are used in, you can know the product release on the production line. What problem or exception happen to build every product historical records, so when the product is delivered, it can still be traced back the components and processes used in the original production of each product.

11. Performance Analysis: One of the most important functions of MES. This feature instantly compares. Performance analysis reports for current operations and historical records. Provide process information, quality parameter data, production scheduling consistency of information, resource optimization, availability and product life cycle information. These messages are available online as timely or periodic reports to evaluate production lines activity.

2.3 Smart Manufacturing

Smart manufacturing: the large amount of data used includes the amount of raw materials stored, the production speed of the machine, the location of the dispatch and other more. Big data enables smart factories to map out a virtual picture of how an entity works to perform predictions results and making autonomous decisions. The construction of a smart manufacturing can improve the understanding of smart factories. In response to the high competition in the manufacturing industry, the cooperation between man and machine can be improved through the full automation of the factory. To enhance the competitiveness of traditional industries, it is necessary to transform traditional industries into digital, AI, RPA (process robot automation), and form a smart manufacturing with fewer people.

R. Shivdas [7] explores a next-generation manufacturing perspective, integrating the trends of smart manufacturing, Industry 4.0, and Reconfigurable Manufacturing Systems (RMS). Through an industrial case study on RMS part family formation, the author elucidates the advantages of adopting RMS over existing

manufacturing systems. S. Wang et al. [8] propose a smart factory framework based on a multi-agent system, integrating industrial networks, cloud computing, and monitoring control terminals to model shop-floor entities—such as machines, conveyors, and products—as distributed agents, with a cloud-based coordinator enabling data-driven feedback and dynamic coordination to construct a manufacturing system characterized by high flexibility and self-organization.

Under the high competition of globalization, the traditional industry is facing a crisis to solve the problem by building a smart manufacturing. Through the networking of the smart manufacturing, the factory automation is combined with the MES manufacturing execution system, and the basic equipment of the factory is improved to make the production process smoother. Improve the optimization of factory operation. As shown in Fig. 1, to realize smart manufacturing, the corresponding mechanism must be established first. The concept is that the information system runs through the management of the factory, and the structure of the system outline of the smart manufacturing. The top layer is the information system of the factory management, which manages the business information of the enterprise, such as financial management, and establishes KPI key performance evaluation standards. On the next level is the basic system of the factory. The original ERP system installed in the factory, and below that there are Sensors-based MES manufacturing execution system and SFC manufacturing site control and other equipment.

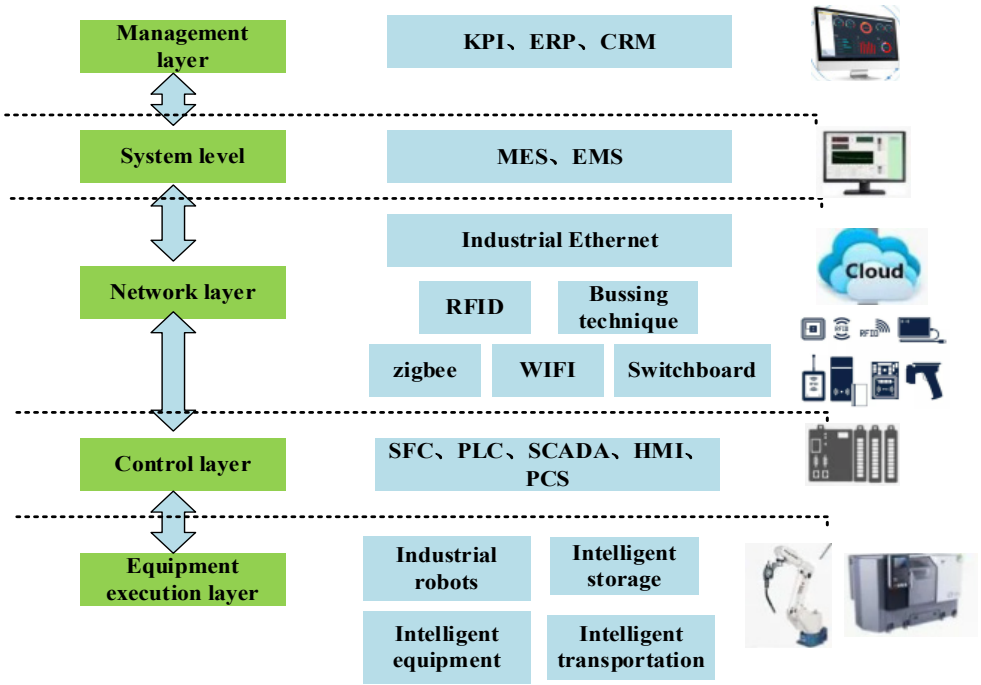


Fig. 1. The system framework of the smart factory

Advantages of building a smart manufacturing:

1. Manpower simplification and labor saving: Only manpower needed to manage machines and information systems, save time and energy.

2. Visualization of the manufacturing process to predict machine equipment failures, reduce defect rates, and speed up production, increase production, etc., thereby reducing production costs.

3. Comprehensive information is provided in automated data, and managers or decision makers of manufacturing companies will have easier access to wealth of information available for advanced production analysis, which information can be used to implement the plan and measure performance.

4. Improve product quality: virtualize digital twin physical assets and processes, etc. Valuable items, which can continuously monitor the product before it is launched product quality.

5. Reducing production costs: it can support this work to provide predictive maintenance.

The core technology is imported into artificial intelligence and Sensors-based MES manufacturing execution

system, and the traditional technology system is upgraded to the Internet. Synthesize the definitions of smart factories by various scholars. The operation of a smart manufacturing is driven by data. D.S. Kabilova and G.G. Bazarbaeva [9] have investigated the design and development of a manufacturing execution system (MES) software interface for garment production management, aligning with multi-level user requirements, adhering to usability and simplicity design principles, integrating real-time data and external system connectivity, and utilizing user feedback for iterative optimization—significantly improving production efficiency and quality control while reducing costs, thereby delivering a practical digital interface paradigm for flexible garment manufacturing in Industry 4.0.

J. P. Kelly [10] believes that in the era of smart manufacturing, as artificial intelligence continuously enhances the capabilities of digital twins, the reliability of data becomes increasingly vital, and data standardization grows ever more critical. Digital twins, leveraging massive volumes of AI- and IoT-generated data to real-time mirror physical systems, derive their enhanced effectiveness from these data-driven mappings, making data reliability and standardization the cornerstone of any successful enterprise data strategy.

Due to the rapid evolution of Internet of Things (IoT), the advantage of having smart manufacturing has been quickly recognized by the industry. Manufacturing companies are facing challenges of organizing an unprecedented technical integration of systems and factories across hierarchy, domain boundaries and life cycle phases. X. Shi et al. [11] provided insights that help the manufacturing companies toward developing a practical process to achieve the ultimate goal of interconnecting every step of their smart manufacturing. Case-study that lower the entry barrier, and reduce the investment risk of the transformation process for the factory automation system is highlighted and validated.

Focusing on the core topic of the transformation of the manufacturing industry from Industry 4.0 to Industry 5.0, P. Cao and J. B. Jamal [12] first analyzed the background and challenges of the transformation. Then they deeply dissected the core elements and architectural design of the DTx strategic model. Finally, they verified the effectiveness of the model through empirical research. This study not only provides theoretical guidance for manufacturing leaders, but also offers a practical path for reference in the transformation and upgrading of the manufacturing industry.

In the face of problems in industrial development, in terms of strengthening the speed of industrialization of new technologies, China's industrial development will emphasize the combination of AIoT, AI, Big Data, 3D printing, AR/VR and other new technology research and development and application, through the application of ICT technology, to break through the current Production bottlenecks are more efficient, smarter, more energy-saving and manpower-saving to meet market demand while maintaining environmental sustainability.

2.4 Analysis of Critical Success Factors

The manufacturing industry not only has to face complicated environmental protection laws and regulations, but also low-price competition in the mainland, lack of domestic labor, high awareness of environmental protection among the people, and high-tech quality demands, so that the manufacturing industry is facing serious bottlenecks. In the face of global competition and high-level challenges, how to enhance the competitiveness of the manufacturing industry, construct the digitization of various systems in the factory, shorten the factory's process, and enhance the advantages in the industry. For the manufacturing industry, how to find key success factors to solve manpower problems, smooth manufacturing process, and increase production capacity has become an important issue. To operate successfully, an enterprise must discuss its own advantages. The only way for an enterprise to succeed is to master its own key success factors in order to establish its own advantages. Point out the variables or conditions or characteristics that can cause the success of the enterprise, and these variables can be implemented with the consent of the business relationship, called the key success factors.

Steps for critical success factors:

1. Determine the strategic goals of the enterprise.
2. Identify all success factors: mainly analyze various factors that affect strategic goals and sub-factors that affect these factors.
3. Identify critical success factors. Critical success factors vary from industry to industry. Even organizations in the same industry have different critical success factors due to the differences in their external environments and internal conditions.
4. Define the performance indicators and evaluation criteria for each critical success factor.

Observing the actions of enterprises, we found that we need to make the right choice in the decision-making of enterprises. These factors that affect the performance of the enterprise are the ability combination of the

enterprise, also known as the critical success factor. For any industry to be successful, there must be 3 to 6 reasons for success. An industry must explore and seek its critical success factors in order for the enterprise to move towards the goal of success. Think of the key factors that affect the enterprise, find out the internal and external factors that affect the enterprise, and carefully deal with the factors that threaten the enterprise.

2.5 Critical Success Factor Concepts

Factor 1: Factors that must be identified and dealt with carefully, either internally or externally, because These factors will affect the achievement of business goals and even threaten the survival of the business.

Factor 2: These factors, which must be given special attention, have a significant impact on the business.

Factor 3: It can be internal or external to the enterprise, and its impact may be positive or negative.

Factor 4: Special attention must be paid to the familiar to avoid unexpected situations or missed opportunities.

Factor 5: It can be confirmed by evaluating activities such as corporate strategy, environment, resources, and operations.

The key factors for the success of an enterprise must start from the strategy used by the enterprise, formulate the opportunity for the enterprise to win from the powerful resources and favorable activities of the enterprise, and use the planning of the enterprise from the overall economic aspect, the environmental aspect and the enterprise itself discuss its critical success factors. The key elements that can affect the operation of the enterprise and make the enterprise profitable. The factors that will threaten the development of the enterprise must be carefully dealt with, and discussed from the inside and outside of the enterprise, because these key factors are the main factors for the success of the enterprise. The key success factors will allow the company to survive in the market and hold resources that are beneficial to the company. To be successful, a company needs to use precise analysis to find out how it can compete with other companies and improve the company's success indicators.

The main sources of critical success factors:

1. The structure of individual industries: Different industries have different characteristics and structures due to their own characteristics. Critical success factors, which are determined by the operating characteristics of the industry itself characteristics, every company in the industry must pay attention to these factors.

2. Competitive strategy, industry: The industrial status of an enterprise is determined by its past history and current competitive strategy. Determined by the position and geography in the industry, each company in the industry has a different competitive position,

The location and the critical success factors will also vary, firm-dominated industries, the actions of leading firms are often small companies pose big problems, so for small companies, big company's competitor's strategy is the key success factor for its survival in the competition.

3. Environmental factors: Changes in the external factors (overall environment) of the enterprise will affect each critical success factors of the company. If the market demand fluctuates greatly, the storage goods control may be considered by senior executives as one of the critical success factors

4. Temporary factors: are mostly due to special reasons within the organization, which are an area of activity that has had a significant impact on an organization's success at a given time.

The success of an enterprise must take stock of the resources available to the company, and any factors that may cause the success of the enterprise must not be given up, and avoid the loss of the enterprise caused by the asymmetry of resources. In the midst of fierce competition, the ability to sell through business allows enterprises to obtain a large amount of added value and professional technology, and obtain the key success factors by finding professional technology. The key success factors affecting the enterprise are: whether the enterprise has sufficient capital; whether the enterprise has drawn up future goals; whether the value of the enterprise's own customers can be grasped; whether the quality of the products is recognized by customers.

Critical Success Factors Affecting Businesses:

1. money
2. future direction
3. sustainable development
4. talent
5. customer value
6. Strategy
7. Quality
8. Smart capital
9. new product open

Observing the actions of enterprises, can found that it need to make the right choice in the decision-making of enterprises. These factors that affect the performance of the enterprise are the ability combination of the enterprise, also known as the critical success factor. The success of an enterprise must take stock of the resources available to the company, and any factors that may cause the success of the enterprise must not be given up, and avoid the loss of the enterprise caused by the asymmetry of resources. Enterprises do not pay attention to the key areas of enterprise success. If the enterprise fails to implement these known key success factors, it will cause the enterprise to fail to achieve its due goals. To be successful, a company needs to use precise analysis to find out how it can compete with other companies and improve the company's success indicators. The main sources of critical success factors:

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4. Temporary factors are mostly due to special reasons within the organization, which are an area of activity that has had a significant impact on an organization's success at a given time. CSF: is the English expression of the key success factor. Success is the core of the enterprise and the purpose of the key success factor. Achievement is the success of the enterprise. The so-called success is to achieve the mission and goals of the enterprise, and making up your mind, using the right method, and choosing a good strategy are the key success factors.

3 Research Methods

3.1 Research Framework and Hypothesis

The manufacturing industry uses the MES manufacturing execution system to construct the key success factors of the smart manufacturing to explore the correlation research, and then draws up the research framework, as shown in Fig. 2.

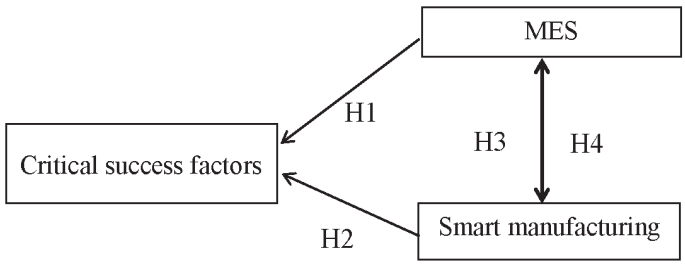


Fig. 2. Research architecture

Based on the current development status of the manufacturing industry, this study explores the key success factors for constructing smart factories using MES manufacturing execution systems, and establishes hypotheses by understanding the relationship between them. This study assumes the following:

H1: The use of MES manufacturing execution system in the manufacturing industry has a positive impact on critical success factors.

H2: The construction of smart factories in the manufacturing industry is positively related to key success factors.

H3: The use of MES manufacturing execution system in the manufacturing industry is positively related to the construction of smart factories.

H4: The construction of smart factories in the manufacturing industry is positively related to the use of MES manufacturing execution systems.

3.2 Research Object and Questionnaire Design Framework

The main object of this research questionnaire is the discussion on the use of MES manufacturing execution system, the construction of smart factories and the key success factors in the manufacturing industry. They are very conservative in themselves, and there are certain difficulties in distributing the number of questionnaires. We can only objectively explain the meaning of filling out the questionnaires. This study adopts the questionnaire survey method, which is one of the widely used methods in the current research. In the questionnaire survey method, the design of the questionnaire itself is very important, which is related to whether the topic of this paper can be accurately asked. The design of this questionnaire is based on the literature of scholars to extract the relevant variables of this paper, and discusses the application of MES manufacturing execution system in the manufacturing industry, the construction of smart factories and key success factors. Manufacturers are the targets of the questionnaire.

After the questionnaires were collected, this research used the Likert five-point 1 scale in the analysis tool vendor. This scale is widely used in psychology-related research. The Likert scale is divided into five items (1=strongly disagree, 2=disagree, 3=no opinion, 4=agree, 5=strongly agree). Due to the small scale of the manufacturing industry, most of whom are small and medium-sized enterprises, the industry itself is very conservative, and there are certain difficulties in distributing the number of questionnaires. We can only answer the questionnaire objectively. The questionnaires for this study start in 2021, and the questionnaires will be answered anonymously and anonymously. In this study, a total of 245 questionnaires were distributed and 210 were recovered, 15 invalid questionnaires were excluded, and 195 valid questionnaires were returned, with an effective recovery rate of 85.7%.

3.3 Research Tools

The data analysis tool of this study is to use SPSS software for empirical analysis. The data analysis methods used include descriptive statistics, independent sample t-test analysis, correlation analysis, reliability analysis and other methods.

1. Statistical Analysis

Descriptive statistics are also collectively referred to as descriptive statistics. Descriptive statistics describe the statistical keywords of a variable, such as percentages. Use statistical methods to describe the research data itself and the related variables of this study. Descriptive statistics mainly compare the degree of dispersion, central tendency and correlation of data. When researchers want to discuss the data distribution of category variables, the frequency distribution table is a more appropriate choice. In the sample data of this study, gender, marital status, whether there are children, age, education level, and service years are all suitable. Variables in the distribution table of execution times. Explore the relationship between its variables. In this study, based on the questionnaire data, the average and standard deviation analysis, percentage, frequency distribution and other analysis were carried out.

The personal background variables of the samples, such as age, monthly income, educational background, gender, marriage and other demographic variables, were analyzed by questionnaire design.

2. t-test for Independent Samples

It means that two samples are independent of each other and have no relationship with each other. Two independent samples each receive the same measurement. The main purpose is to measure whether gender causes a significant difference, so as to understand the impact on the research variables. In this study, the t test is suitable for the test of the mean of two samples, to compare the difference between the mean of two mothers with the same variation, or to compare the difference of the mean of two samples from the same mother. In this study, the t-test is used to test whether the business strategy of the enterprise is significantly different due to

differences in gender variables. Defining independent samples t-test: The comparative distribution used by the dependent-samples t-test is that each person has two sets of scores, and the distribution of mean times under this difference score. (Score <=>Score) the mean number of distributions independent samples t test, when the scores come from two different groups of people, only the average of one group of people can be compared with the average of another group of people, that is, the difference between the averages of the two mother groups, so the comparison distribution is the difference in the average distribution of times.

3. Reliability and Validity Analysis

Reliability often refers to reliability in papers. The data presented by the software is stable and consistent, and has reference value. Reliability and validity analysis: The use of statistical tools in the variables in the study to prove the relationship between the variables is called calibration validity. In this study, Cronbach's α was used to measure the internal consistency of each variable questionnaire. When $\alpha < 0.35$ represents low reliability, $0.35<\alpha<0.7$ represents medium reliability, and $\alpha \geqq 0.7$ represents acceptable high reliability. In practice, if $\alpha \geqq 0.6$, the confidence of the measurement work can be declared degree is acceptable.

4. Correlation Analysis

In statistical analysis, the size of the sample size is related to the significance of the correlation coefficient. In statistics, the number of samples sampled in this paper is large, even if the value of the correlation coefficient is small, its significance is easy to show. Therefore, in the interpretation process of correlation analysis, in addition to explaining In addition to whether the two variables are significantly correlated, the size of the coefficient of determination should also be presented and explained. Pearson's theory: If the correlation between the X variable and the Y variable is 0.50 ($p<0.001$), the coefficient of determination is 0.25, which means that "in the variation of the Y variable, the percentage of the variation that can be explained by the X variable is 25% while the correlation coefficient is equal to 0.50, it means that there is a significant difference between the X variable and the Y variable positive correlation.

When both variables are continuous variables, we want to know the relationship between one thing and another thing, we must use correlation analysis to analyze the degree of correlation between the two variables. The correlation coefficient is mainly to test the degree of correlation between variables. The size of the correlation coefficient (r value) can reflect the strength of the correlation between two variables, but it does not test the influence of the independent variable on the dependent variable. It can only indicate whether the two variables are positively correlated, negatively correlated, or irrelevant. The correlation coefficient The strength of the large relationship is high, and the strength of the relationship is low if the correlation coefficient is small. For the degree of correlation and the degree of correlation coefficient between the variables of the degree of correlation as Table 1.

Table 1. Correlation coefficient and degree of correlation

Correlation coefficient (r)	Degree of correlation
0.8 Above	Extremely high
0.6-0.8	high
0.4-0.6	normal
0.2-0.4	low
0.2 Below	Very low

5. Analysis of Pretest

After the completion of the questionnaire design, in order to know whether there is any deviation and difficulty in the content of the questionnaire itself, which makes it difficult for the respondents to fill in the answers, and causes the respondents to answer randomly and produce invalid questionnaires, this research asked about 20 employees of the company in advance to deal with the MES. Workers who have a concept of manufacturing execution system and smart manufacturing, check the difficulty of the questionnaire first and help to answer it. Distribute 20 returned valid questionnaires 20, the effective recovery rate is 100%, and the respondents' suggestions are used to modify the items of the questionnaire content, and the reliability and validity of the questionnaire are analyzed after the questionnaire is recovered. The Cronbach's a reliability coefficients above 0.9 have good reliability.

4 Results and Analysis

4.1 Statistical Analysis

Due to the small scale of the manufacturing industry, most of whom are small and medium-sized enterprises, the industry itself is very conservative, and there are certain difficulties in distributing the number of questionnaires. We can only answer the questionnaire objectively. The questionnaire for this study will be distributed in 2021, and the questionnaire will be answered anonymously and anonymously. In this study, a total of 245 questionnaires were distributed and 210 were recovered, 15 invalid questionnaires were excluded, and 195 valid questionnaires were returned, with an effective recovery rate of 85.7%. Among the valid questionnaires collected by this research, most of the respondents are men because they are related to the manufacturing industry.

Regarding the age part, due to the nature of the work in the manufacturing industry and the relationship between the working environments, young workers have a relatively low acceptance of the manufacturing industry. According to the data, it is found that the middle and high age groups are the majority, and the proportion of people over 50 years old is as low as 27%. , and the proportion of those under the age of 50 is 73%. This study found that 22% of the respondents were over 56 years old at most, and less than 1% were under 25 years old at least. This shows that the manufacturing industry urgently needs young people to join in manpower demand. There is also an urgent need to build a smart manufacturing to solve the problem. For the part of marriage, this research found that the manufacturing industry got married later due to the nature of work, but almost all of them were married. 84.3% of the respondents who were married were far more than 15.7% who were unmarried. The manufacturing industry often needs to work overtime due to the nature of the work, and because the salaries given by the technical work-oriented enterprises are not low. Although the manufacturing industry is a traditional manufacturing industry, because of technology-related issues, education generally falls on university graduates, accounting for 73%, and master's degrees account for 13%. High school vocational education accounted for a relatively small proportion of 13%.

4.2 Independent Sample t-test Analysis

The analysis o based on the basic information of the gender and marriage questionnaires, statistical software is used for independent sample t-test analysis, and the Lavene test can be used to understand whether the variance assumptions affecting the results in this paper are the same or different. Table 2 is based on the gender-independent sample t-test analysis of the paper, using the Lavene test, found that women and men were in the MES manufacturing execution system, intelligence. There is no relatively obvious difference in the data generated and critical success factors. Table 3 shows the t-test analysis of independent samples of marriage in this paper, using Lavene test to find. Now there is no relatively significant difference in the data generated by women and men in MES manufacturing, smart factories, and critical success factors as Table 2.

Table 2. Gender independent sample t-test analysis table

Gender		Number	Mean	Standard deviation	Standard error	t-value
MES	1 (male)	110	3.290	0.641	0.061	-4.723
	2 (female)	85	3.711	0.585	0.063	
Smart factory	1	110	3.017	0.759	0.072	-4.405
	2	85	3.484	0.698	0.076	
Critical success factor	1	110	3.192	0.655	0.062	-3.806
	2	85	3.54	0.606	0.066	

Table 3. Marriage independent sample t-test analysis table

Marriage		Mean	Standard deviation	Standard error	t-value
MES	0 (unmarried 73)	3.16	0.68	0.08	-5.589
	1 (married 122)	3.66	0.556	0.05	
Smart manufacturing	0 (73)	2.875	0.809	0.095	-4.928
	1 (122)	3.428	0.663	0.06	
Critical success factors	0 (73)	3.055	0.709	0.083	-4.749
	1 (122)	3.516	0.556	0.05	

4.3 Reliability and Validity Analysis

To assess the randomization of the questionnaire, this study employed statistical software to validate content reliability and ensure analytical accuracy. Cronbach's α coefficient was used to evaluate internal consistency: a value below 0.35 indicates low reliability, 0.35–0.7 signifies moderate reliability, and ≥ 0.7 represents acceptable high reliability. In practical applications, a reliability coefficient ≥ 0.6 is considered sufficient. For the reliability analysis of three variables— "MES Manufacturing Execution System," "Smart Manufacturing," and "Critical success Factors" —Table 4 shows that the Cronbach's α coefficients for the three measurement items—MES Manufacturing Execution System, Smart Manufacturing, and Critical Success Factors—showed excellent internal consistency reliability ($\alpha \geq 0.9$) across all subjects, with reliability coefficients of 0.969, 0.97, 0.963, 0.968, and 0.962 for the male, female, unmarried, and married groups respectively. This indicates strong inter-item correlations, confirming these items' ability to reliably measure the same construct. Data analysis indicates that all variables demonstrate high reliability levels, as detailed in Table 4.

Table 4. Reliability coefficient table

Reliability type	Sample size (n)	Cronbach's α	Confidence level
General Reliability (all subjects)	195	0.969	Very reliable ($\alpha \geq 0.9$)
Male group reliability	110	0.97	Very reliable ($\alpha \geq 0.9$)
Female group reliability	85	0.963	Very reliable ($\alpha \geq 0.9$)
Unmarried group reliability	73	0.968	Very reliable ($\alpha \geq 0.9$)
Married group reliability	122	0.962	Very reliable ($\alpha \geq 0.9$)

4.4 Correlation Analysis

According to Pearson's correlation analysis table, the relationship between the variables of each dimension is discussed, and the correlation between each other can be understood from the statistical analysis data. Discussing the correlation between the various aspects, it can be seen from Table 5 that the correlation coefficient between the MES manufacturing execution system and the smart manufacturing is ($r=.933$, $p<0.01$), which shows that it is very significant. As the core, the probability of success is very high. The improvement of the manufacturing industry must apply the MES manufacturing execution system and build a smart manufacturing to improve competitiveness. The correlation coefficient between the MES manufacturing execution system and the key success factors is ($r=.910$, $p<0.01$), which shows that it is very significant. The key success factor of the manufacturing industry is to use the MES manufacturing execution system to improve the production capacity of the factory, make the process smooth, and reduce the defective rate happened. The correlation coefficient between the smart manufacturing and the key success factors ($r=.921$, $p<0.01$) shows that it is very significant. The manufacturing industry belongs to the traditional manufacturing industry. Due to the nature of the work and the working environment, it is not easy to hire employees. The manufacturing industry is facing a strong opponent, the Southeast Asian countries, the key success factor is to increase the MES manufacturing execution system equipment to build a smart manufacturing, increase production capacity and improve product quality is the only way. For the relationship between variable facets, refer to Table 5.

Table 5. Correlation coefficient table between facets and facets

Facet	MES	Smart manufacturing	Critical success factor
MES	1	0.933**	0.910**
Smart manufacturing	0.933**	1	0.921**
Critical success factor	0.910**	0.921**	1

**The correlation is significant at a significance level of 0.01 (two-tailed).

5 Conclusion and Future Work

5.1 Conclusion

Most manufacturing industries stay in the traditional manufacturing mode, and most of the data collection adopts a manual operation mode, so that manual and paper statistics are used in the process from purchase to production and warehousing, and then the production staff makes daily collection records. Because it is impossible to know the production status of the factory in real time, and it is impossible to implement real-time effective control on the site. In addition to consuming a lot of manpower and making it difficult to obtain labor, a large amount of hazardous substances are used in production, which not only pollutes the environment, but also cannot effectively control costs and avoid Waste and control of the amount of waste liquid pollution, so that it is impossible to leave the market under low cost, high competition, and high environmental awareness. Manufacturing is due to lack of labor, personnel training needs to be improved, high investment in automation equipment, traditional production, difficult to grasp orders, and manufacturing processes. Pollution, complicated environmental protection laws and regulations, continuous improvement of quality requirements, poor working environment and other difficulties have caused the traditional manual production line to be gradually eliminated. This paper studies the key success factors of the manufacturing industry using the sensors-based MES manufacturing execution system to construct a smart manufacturing to solve the current plight of the manufacturing industry.

Research Hypothesis Research Results:

Hypothesis 1: The use of MES manufacturing execution system in the manufacturing industry has a positive impact on critical success factors.

Hypothesis 2: The construction of smart factories in the manufacturing industry is positively related to key success factors.

Hypothesis 3: The use of MES manufacturing execution system in the manufacturing industry is positively related to the construction of smart factories.

Hypothesis 4: The construction of smart factories in the manufacturing industry is positively related to the use of MES manufacturing execution systems.

This study highlights the critical role of sensor-based MES in addressing the challenges of traditional manufacturing, such as real-time data gaps, labor shortages, and environmental pollution, by enabling smart manufacturing through enhanced data collection and control. Compared to existing research, which often focuses on discrete manufacturing or general MES implementation factors, this study uniquely targets process industries like surface treatment, emphasizing ERP-MES integration to streamline operations and reduce waste—a gap less explored in prior literature. The findings align with broader smart manufacturing trends, where real-time control and system interoperability are pivotal for efficiency. Theoretically, it underscores the necessity of integrating technological advancements with organizational readiness. Managerially, it stresses the importance of process re-engineering and strategic planning to overcome resistance to change. Practically, it offers actionable insights for industries to adopt sensor-based MES, thereby improving competitiveness and sustainability amidst stringent environmental regulations and rising quality demands. This study thus bridges academic knowledge and industrial application, providing a roadmap for digital transformation in underserved sectors.

5.2 Future Work

This study found that the use of sensors-based MES manufacturing execution system can enable enterprises to increase the overall production capacity, and reduce the shortcomings of machine and equipment downtime

in the factory, and improve the overall operation of the enterprise to improve competitiveness. The enterprise achieves the effect of shortening the product cycle, shortening the filing time, reducing the amount of paperwork in the enterprise, and reducing defective products. Based on the research of this paper, we propose the following future work.

1. While this study employs questionnaire surveys and t-test analyses to explore the relationship between sensor-based MES adoption and smart manufacturing outcomes, its cross-sectional design inherently limits causal inference. To address this, future research should incorporate experimental designs or time-series analysis to strengthen causal validity. Experimental methods, such as controlled trials in selected manufacturing sites, can isolate MES effects by manipulating variables while holding others constant. Alternatively, time-series analysis of longitudinal data from multiple periods would enable tracking changes in efficiency and environmental impacts before and after MES implementation, thereby clarifying causal pathways. These approaches will enhance the robustness of findings, offering clearer insights into how MES drives smart manufacturing transformation.

2. The government should provide special subsidies to small and medium-sized manufacturing enterprises to increase equipment investment. Due to their generally small scale and conservative development, these enterprises often lack the financial capacity to purchase sensor-based MES (Manufacturing Execution Systems) for intelligent manufacturing. The government should extend a helping hand through special funding and low-interest loans to help them enhance their competitiveness.

3. Professional Upskilling: To compete with Southeast Asia's labor cost advantage, China's manufacturing sector must focus on quality. Government and industry bodies should provide regular training to upgrade workers' skills.

4. Counseling manufacturing international certification international certification: Leverage the power of industry, government and academia to guide the shortage of professional and high-level technical manpower in the manufacturing industry, and assist the industry to pass relevant certificates to achieve quality certification.

5. Government guidance to develop the international market: More than 90% of the manufacturing industry is sold domestically. It is suggested that the government guide manufacturers to go international and improve the interests of enterprises.

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