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Exploring the Success Factors of Digital Transformation in the Footwear Industry towards Industry 4.0: A Delphi Study

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ABSTRACT : This study explores success factors of digital transformation of a traditional manufacturing. Having one of the strongest supply chains in the world, the retail footwear industry has been drastically changed in the past few decades. How does the footwear industry go through the process of digital transformation is of interest. Using the Delphi method, this study investigates the main issues that footwear industry facing and the solutions of meeting customer demands and market competition.
Delphi method was used and data collected from 20 experts were analyzed. The results indicate that digital transformation is the most effective aspect of Industry 4.0 technologies, particularly in digitization, efficiency, optimization, and integration. However, experts highlight fundamental difficulties in digitization, especially in knowledge:transfer from experienced craftsmen, emphasizing the importance of talent cultivation and protection.

KEYWORDS: Digital Transformation, Knowledge transfer, footwear industry, Industry 4.0

I. INTRODUCTION

Taiwan's footwear industry was once one of the leading export industries globally, earning the title of "Kingdom of Shoes" (Lin, 2003). However, due to rising labor costs and market changes, many footwear manufacturers had to seek overseas factories to maintain their competitiveness.
Taiwanese shoe manufacturers need to improve quality and production efficiency while reducing costs to remain competitive internationally, because of globalization and the high competition in international market. Taiwan manufacturers observe international market demands, examine the development of international division of labor, and increase their technological and R&D capabilities, continually innovating their design capabilities. Learning from the channel building and brand management of international brands helps establish the conditions for global operations and management capabilities in international competition (Liang, 2013).
The footwear industry is labor-intensive; thus, it faces challenges in automation and applying smart technologies. Becuase of globalization and environmental protection, human rights organizations, material restrictions, and regulations in Europe and the United States, the footwear industry has gradually move to the ASEAN region such as China, Vietnam, Indonesia, and Bangladesh (Hsieh, 2019). These countries leverage their demographic dividends and advantages as developing nations to gradually become important production bases for the footwear industry. However, with large international tech companies settling in these regions, local labor wages have been risen, labor rights awareness has increased, and government policies have changed, leading to a decline or even regression in the operating income of the footwear industry. This forces the footwear industry to reconsider relocating production bases and continue to refine technology, reduce labor, and improve processes to cope with challenges.

The footwear industry in Taiwan faces challenges in production automation and intelligence. The processes in the footwear industry are difficult to operate automation and smart technologies. It highly relies on manual operations, making the goal of automation hard to achieve. Even if leading companies in the footwear industry conduct bold experiments, they may not completely replace human labor. The production of sports shoes is becoming more complex, with a higher proportion of manual labor than before, making the rate of automation adoption low (Liang, 2021). Smart manufacturing does not solely rely on machines to replace human labor but uses data digitization to enhance design, production, service efficiency, reduce costs, and improve quality (Liang, 2021). Through smart manufacturing and data management, the footwear industry can make progress in design, production, and services, lowering costs and improving quality.

This background has scant research on the success factors of the footwear industry. We intend to take the perspective of Industry 4.0 (introduced by the Hannover Messe in 2011, it has become a key part of national strategies, though its resource demands are typically sustainable only by nations or large enterprises). to explore the specific benefits of existing Industry 4.0 technologies in the footwear industry, examine the application prospects and challenges of undeveloped Industry 4.0 technologies in the footwear industry, and investigate the key factors that footwear companies need to consider when implementing Industry 4.0 technologies. We hope to provide valuable insights and recommendations for the development of the footwear industry.

II. LITERATURE REVIEW

The development of Industry 4.0 involves keywords from multiple fields, covering management, culture, and sustainability. We adopted the concept from "Sustainable industrial and operation engineering trends and challenges Toward Industry 4.0: a data-driven analysis," in which recent years' literature on Industry 4.0 were analyzed by used software (Tseng et al., 2021). The frequently mentioned keywords (such as lean manufacturing, big data, cloud computing) were identified in the study. Due to the large number of keywords, using too many can distract our experts when giving answers to questionnaires; we used some of the keywords from the literature results as valid terms.

The Fuzzy Delphi Method (FDM) was used for analysis and clustered various field indicators. In the context of advancing Industry 4.0 and sustainable industrial ecosystems and operational engineering, we identified 30 indicators and divided them into eight research groups. These clusters help understand the trends and challenges in the process of Industry 4.0. The identified indicators include lean manufacturing, decision support system, digitalization, efficiency, integration, big data, cloud computing, energy efficiency, information technology, internet of things, wireless communication, cyber-physical systems, optimization, smart manufacturing, sustainable manufacturing, human factors, safety, security, blockchain, artificial intelligence, innovation, sustainability, circular economy, digital transformation, business intelligence, deep learning, machine learning, virtual reality, environment sustainability, and smart city.

These keywords frequently appear in the literature, reflecting the focus and development trends of current research on Industry 4.0. This helps understand the diverse aspects of management, culture, and sustainability in this field (Culot et al., 2020; Barrios et al., 2021; Nasa et al., 2021).

III. RESEARCH QUESTIONS AND METHOD

Research Questions

The main objective of this study is to investigate the success factors and effectiveness of technology applications in the footwear industry's transition towards Industry 4.0. Based on the previously discussed research background and motivation, the research purposes are as follows:

1. To analyze the benefits of currently applied Industry 4.0 technologies in the footwear industry,
2. To explore the expectations and challenges of underdeveloped Industry 4.0 technologies within the industry, and
3. To examine any additional issues related the success factors of Industry 4.0. Through the Delphi study, we intend to resolve the following research questions: R1: What are the specific benefits of currently applied Industry 4.0 technologies? R2: What is the potential of underdeveloped Industry 4.0 technologies?

R3: What are the main challenges and difficulties faced by the footwear industry in implementing Industry 4.0 technologies?

R4: What key factors should footwear companies consider when implementing Industry 4.0 technologies?

R5: What are the key success factors for achieving Industry 4.0?

Method

The Delphi Method is used in this study. It is a structured communication technique used for systematic, interactive forecasting by a panel of experts. Its advantage lies in its ability to reach a consensus among experts and develop professional guidelines, and it has been widely applied in fields such as clinical medicine, public health, and business forecasting (Linstone & Turoff, 1975). The method is based on the principle that structured group predictions are more accurate than unstructured group predictions (Rowe & Wright, 1999). Experts answer questionnaires in rounds, and after each round, anonymous summaries of the experts' predictions and the reasons for their judgments are provided. This encourages the experts to revise their answers based on the responses from other members of the panel, aiming to achieve consensus. Studies have shown that controlled feedback significantly influences the change in expert opinions (Barrios et al., 2021).

Van Nguyen et al. (2022) explored the key factors and specific indicators for implementing the TQM 4.0 model in manufacturing enterprises using the Delphi Method and Analytic Hierarchy Process (AHP) based on Socio-Technical Systems (STS) theory. Through two rounds of Delphi analysis, they identified 10 factors and 41 indicators that provide specific references for the application of Industry 4.0 technologies in manufacturing.

Drumm et al. (2022) noted that the use of Likert scales allows experts to give more honest feedback under anonymous conditions, enhancing the inclusiveness of the survey. Culot et al. (2020) pointed out that literature on Industry 4.0 is still fragmented, and the emerging paradigm seems to be a controversial area between different disciplines. This study also notes this point and includes aspects of management, culture, and sustainability.

Research Design

This study employs literature mining to identify the most recent hot topics in the development of Industry 4.0 and examines the context of the Taiwanese footwear industry's expansion overseas and its progression towards Industry 4.0. A panel of experts with relevant knowledge and experience participate in anonymous surveys to reach consensus standards. Two rounds of questionnaires were conducted to analyze whether there is consensus or divergence on the current context. The data collections were conducted during Aug, 19-25, 2024 (round 1) and Aug, 26-28, 2024 (round 2) with all 20 participants rely to the questionnaires.

Participants

The participants of this study are senior management personnel from the footwear industry who have practical experience in executing Industry 4.0 strategies in their companies. Data collection were facilitated through contacts the researcher established during large projects. Some experts still maintain contact via LINE or WeChat. Additionally, we enlist the help of former company assistants to invite lesser-known experts to participate and offer survey incentives to ensure their cooperation. They are top and middle management with 4-20 years of experience in footwear industry, education level ranging from college to Ph.d.

Data Collection and Analysis

Data will be collected using Google Forms distributed to the selected experts. The survey is anonymous and a structured questionnaire was used. Data analysis was conducted using IBM SPSS version 29.0.2.0 (20). A Likert-type scale was used, and the data analysis include descriptive statistics, reliability statistics, and consistency checks to ensure data validity and reliability.

IV. FINDINGS AND DISCUSSION

Although various issues of Industry 4.0 have developed to a certain extent, the resources and energy needed to realize Industry 4.0 still mainly rely on national or large enterprise support. This study aims to explore the application and success factors of digital transformation in
Industry 4.0 within the footwear industry, using the Delphi method to collect expert opinions and obtain solutions.

The research findings are as follows:

1. Benefits of Digital Transformation: The digital transformation and efficiency are the most beneficial aspects of Industry 4.0 technologies. Digitalization, efficiency, optimization, and integration are considered the most effective technologies. These technologies not only help improve production efficiency but also enhance product quality, thus maintaining competitiveness in the international market.

2. Challenges: The challenges are lack of digitalization skills, particularly knowledge transfer from experienced craftsmen to less skilled ones. Due to the educational level of these craftsmen not aligning with digitalization, communication is difficult. Hence, talent cultivation and protection become crucial. Many companies view employees as mere labor rather than skilled craftsmen. This has to be changed to promote knowledge transfer and technological innovation.

3. Recognition of Technological Importance: The analysis shows an increased recognition of the importance of technologies such as digitalization, decision support systems, lean manufacturing, big data, cloud computing, and wireless communication. This reflects experts' hopes to facilitate digital transformation, enhance production efficiency, and improve management levels through these technologies. In contrast, the recognition of the importance of technologies such as efficiency, integration, information technology, IoT, cyber-physical systems, and optimization has decreased, indicating an urgent need to strengthen fundamental skills and basic capabilities.

4. Prospects of Industry 4.0 Technologies: The application prospects of Industry 4.0 technologies in the footwear industry are broad, especially in artificial intelligence, automation, and robotics. These technologies will drive the transformation and upgrading of the footwear industry, enhancing production efficiency and product quality. Automation can optimize repetitive tasks, automatic scheduling, program issue handling, and

equipment failure prediction, effectively addressing the challenge of rising labor costs. Data analysis technologies can quickly analyze large amounts of data, discover trends, and provide optimal action plans, thereby improving the efficiency and maintenance of industrial systems and products. Intelligent control technologies can manage all electrical equipment, achieving energy-saving goals.

5. **Major Challenges:** The challenges include high equipment investment, standardization difficulties, data and database issues, and difficulties of human machine collaboration. The substantial capital required for high equipment investments and the long return periods pose significant pressure on traditional industry owners. Problems of standardization arise from the lack of standardization in the footwear industry, making the implementation of Industry 4.0 challenging in terms of standardized and automated manufacturing, production line planning, model establishment, and data collection. Data and database challenges include insufficient databases, difficulties in parameter definition, and the time needed to accumulate effective data. Human-machine collaboration faces the challenge of integrating human and machine operations; automation and robotics in footwear factories are limited, with many fine manual tasks yet to be replaced.

6. **Key Success Factors:** When implementing Industry 4.0 technologies, footwear companies need to consider multiple key factors to ensure a smooth transition and achieve expected outcomes. Investment in digitalization requires sufficient funds and resources. Company culture and employee satisfaction are closely related; a positive company culture helps improve employee satisfaction and work efficiency. Flexible and convenient reforms help enhance employee work flexibility and convenience, attracting and retaining talent. New technologies need to be customized for specific application scenarios upon introduction, which is crucial for improving production efficiency and product quality.

Overall, the application of Industry 4.0 technologies will significantly improve production efficiency and product quality in the footwear industry, helping to address various challenges faced by modern manufacturing and providing more opportunities and development space for the footwear industry.

V. CONCLUSION

The findings suggest that experts recognize the importance of technologies like digitization, decision support systems, lean manufacturing, big data, cloud computing, and wireless communication. However, the importance of efficiency, integration, IT, IoT, cyber-physical systems, and optimization has decreased, indicating practical challenges. While the application prospects of Industry 4.0 technologies in the footwear industry are broad, they face challenges such as high equipment investment, standardization difficulties, data issues, and human machine collaboration. Footwear enterprises must consider digital investment, corporate culture, flexible reforms, and practical technology application to achieve sustainable development.

All in all, the application of Industry 4.0 technologies holds significant potential to enhance production efficiency and product quality in the footwear industry. Addressing the highlighted challenges and leveraging the identified key success factors can provide more opportunities and development space for the industry, ensuring its sustainable growth and competitiveness in the modern manufacturing landscape. Through this approach, we can gain a deeper understanding of the core research areas, thereby contributing valuable insights and advancements to the field.

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