

# The impact of smart manufacturing on the business agility of SMEs in an emerging economy

IIMBG Journal of Sustainable Business and Innovation

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Received 13 October 2024  
Revised 4 July 2025  
26 October 2025  
Accepted 28 January 2026

## Abstract

**Purpose** – The purpose of this research is to empirically investigate the connection between smart manufacturing (SM) and business agility (BA) within manufacturing Small and Medium Enterprise (SMEs), along with the moderating effects of marketing analytics (MA) and the Internet of Things (IoT).

**Design/methodology/approach** – In this research, a survey methodology was employed to gather data from 244 SMEs in the manufacturing sector located in the Eastern Region of Ghana, all of which were registered with the Ghana Enterprise Agency. Through the application of structural equation modelling (SEM) and path analysis, the study investigated the moderating influences of MA and the IoT on the relationship between SM and the BA of manufacturing SMEs.

**Findings** – The findings of this research indicate that the BA of SMEs in the manufacturing sector is positively and significantly influenced by SM practices. Furthermore, the study reveals that MA and the IoT play a substantial and beneficial role in moderating the relationship between SM and the BA of manufacturing SMEs.

**Originality/value** – The findings of the present study provide strong support for the Technology–Organization–Environment (TOE) framework and the theory of dynamic capabilities. Consequently, this study reinforces the concept that, especially within the framework of an emerging economy, manufacturing SMEs ought to consider SM, the IoT, and MA as essential strategic capabilities to enhance their BA.

**Keywords** Smart manufacturing, Internet-of-things, Marketing analytics, Business agility, SMEs, Emerging economy

**Paper type** Research article

## 1. Introduction

Over the last ten years, numerous studies have investigated the evolution of the widely recognized concept referred to as “smart manufacturing” (smart manufacturing (SM)) (Davis *et al.*, 2015; Kang *et al.*, 2016; Kusiak, 2018; Mittal, Khan, Romero, & Wuest, 2019; Wang *et al.*, 2021). As noted by Davis *et al.* (2015), SM was initially characterized as a set of manufacturing methodologies that respond to a new era of interconnected data and information technology capabilities, which are expected to shape manufacturing processes in the future. Over time, previous research has indicated that SM influences various domains, including performance management (Parhi, Joshi, & Akarte, 2021), operational and financial performance of firms (Arcidiacono & Schupp, 2024), as well as manufacturing intelligence and demand-responsive performance (Davis, Edgar, Porter, Bernaden, & Sarli, 2012). A recent investigation by Arcidiacono and Schupp (2024) suggests that to fully harness the



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IIMBG Journal of Sustainable Business and Innovation  
Vol. 4 No. 1, 2026  
pp. 25-58  
Emerald Publishing Limited  
e-ISSN: 2753-4022  
p-ISSN: 2976-8500  
DOI 10.1108/IJSBI-10-2024-0057

value-generating potential of SM, it is essential for business partners to uniformly adopt it. Nevertheless, there exists a lack of sufficient or consistent information regarding the performance-related advantages of SM, which hinders the willingness of organizations, particularly small and medium-sized enterprises (SMEs), to engage with it (Bortoluzzi, Chiarvesio, Romanello, Tabacco, & Veglio, 2022). In a similar vein, the recent systematic literature review conducted by Jaafar, Khan, and Salman (2025) reveals that within the context of SM, business entities face challenges due to the intricate network of factors influencing business agility (BAi), highlighting the need for a comprehensive understanding to effectively navigate this transformative period.

A relatively recent analytical viewpoint in this domain, referred to as “smart manufacturing-enabled business agility,” investigates the interplay between SM and Industry 4.0 technologies (such as the Internet of Things (IoT) and marketing analytics (MA)) and their impact on business agility (BA) (Arden *et al.*, 2021; Mourtzis, 2024; Aloksh, Adedokun, & Iyiola, 2025; Holloway, 2025). While business agility allows manufacturers, particularly in the context of SMEs, to effectively utilize smart technologies, SM enhances BA by enabling quicker responses to market fluctuations and disruptions (Kumar, Singh, & Jain, 2022). Within the framework of SM, data and insights derived from Industry 4.0 technologies, including IoT and MA, empower SME manufacturers to be more responsive to customer demands, adopt new technologies, and address supply chain challenges (Jung, Morris, Lyons, Leong, & Cho, 2015; Potdar, Routroy, & Behera, 2017; Gunasekaran *et al.*, 2019; Bego and Mattos, 2024). According to Lu (2025) and Rehman, Jabeen, Shahzad, Riaz, and Bhatti (2025), Industry 4.0 comprises various technologies that are driving the digital transformation of manufacturing enterprises within the SME sector. Seminal research indicates that by improving data generation and providing real-time insights, Industry 4.0 technologies such as cloud computing, the IoT, MA, and Cyber Physical Systems are fostering the connection between SM and BA (Mrugalska & Ahmed, 2021; Bouchard, Abdulnour, & Gamache, 2022; Agarwal *et al.*, 2023; Sreenivasan, Ma, Rehman, & Muthuswamy, 2023). To facilitate the synergy between SM and BA, for instance, IoT and MA can be employed to collect customer data and disseminate customer-related knowledge throughout the business and SM ecosystem (Javaid, Haleem, Singh, & Suman, 2022; Atieh, Cooke, & Osiyevskyy, 2023).

Research methodologies such as literature reviews, qualitative analyses, conceptual frameworks, and theoretical explorations regarding the influence of SM on various dimensions of BA have constituted the primary emphasis of earlier investigations (Mittal, Khan, Romero, & Wuest, 2018; Mrugalska & Ahmed, 2021; Bouchard *et al.*, 2022). Moreover, there exists a significant lack of quantitative research outcomes concerning the ways in which SM impacts BA, as well as the moderating roles of MA and IoT within the context of SMEs in developing economies. Considering that the predominant portion of the existing literature on this subject is qualitative in nature (Zheng *et al.*, 2018; Mittal *et al.*, 2019; Arden *et al.*, 2021; Kusiak, 2023), this research responds to recent appeals for increased quantitative inquiry into the connection between SM and BA specifically within manufacturing SMEs in an emerging economy, alongside the moderating influence of Industry 4.0 technologies such as MA and IoT (Bortoluzzi *et al.*, 2022; Arcidiacono & Schupp, 2024; Jaafar *et al.*, 2025). To empirically determine the relationship between SM and the BA of SMEs, as well as the moderating effects of IoT and MA, this study will examine 244 manufacturing SMEs located in the Eastern Region of Ghana that are registered with the Ghana Enterprise Agency (GEA). Grounded in the dynamic capability theory and the Technology-Organisation-Environment (TOE) framework, this research seeks to contribute to the existing body of knowledge regarding the interplay between SM and BA in the context of SMEs within emerging economies. The following research questions will be addressed to facilitate this objective.

RQ1. What is the impact of smart manufacturing on business agility?

- RQ2. What is the moderating effect of Internet of Things on the association between smart manufacturing and business agility?
- RQ3. What is the moderating effect of marketing analytics on the association between smart manufacturing and business agility?

Additionally, the current study contributes to the body of knowledge on SM and BA by providing two new viewpoints. First, this study adds to the body of knowledge on SM and BA by conducting an empirical investigation into the relationship between the two within the context of SMEs in an emerging economy. Second, the moderating impacts of MA and the IoT have not yet been considered in the corpus of research on the relationship between SM and BA. This restricts our ability to understand how BA and SM are related. This study advances our understanding of the connection between BA and SM by utilising MA and the IoT as moderating variables. This is how the article is structured. A discussion on the methodology is given after the literature review and research hypotheses are illustrated in the following section. The findings and discussion, along with theoretical or practical ramifications, are then given. Limitations and future research directions are included in the conclusions.

## 2. Literature review and hypotheses development

### 2.1 Theoretical background

*2.1.1 Dynamic capabilities (DC) theory.* Dynamic capabilities (DC) theory provides a framework for understanding how manufacturing SMEs can acquire and sustain a competitive advantage in volatile and uncertain business environments (Ullah, Kukreti, Sami, & Shaukat, 2025). This theory emphasizes the importance of developing organizational competencies that enable manufacturing SMEs to identify and respond to changes in the market, technology, and consumer preferences, particularly within the context of SM and business agility (BA) (Xu, Shahzad, & Hu, 2025). Technologies associated with Industry 4.0, such as the IoT and MA, play a crucial role in linking SM with BA, as they facilitate the creation of intelligent, interconnected systems capable of adapting to evolving customer demands and production needs (Luo, Qu, & Cheng, 2025; Komkowski, Antony, Garza-Reyes, Tortorella, & Pongboonchai-Empf, 2025). The DC theory elucidates how manufacturing SMEs can leverage these technologies to achieve BA. For instance, Hiremath *et al.* (2025) argue that manufacturing SMEs can identify new opportunities and potential disruptions by analyzing data from various sources, including competitor actions, market trends, and customer feedback. This analytical approach allows manufacturing SMEs to swiftly innovate new products, services, and processes to capitalize on opportunities and mitigate risks. Nevertheless, Sufian, Abdullah, and Miller (2025) note that SM often requires significant modifications to existing infrastructure and processes. To successfully incorporate new technologies such as IoT and MA and adapt to changing market and industrial conditions, manufacturing SMEs must realign their resources and capabilities.

According to Xu *et al.* (2025), BA is intricately linked to DC within the framework of SM and Industry 4.0 technologies, such as IoT and MA, as these technologies empower manufacturing SMEs to recognize, seize, and adapt to changes. For instance, manufacturing SMEs can leverage these opportunities by persistently identifying emerging technologies and consumer trends, developing new products and services, and modifying their manufacturing models to align with the evolving market (Lin, Sheng, & Jeng Wang, 2020). Therefore, DC theory provides a valuable lens for understanding how manufacturing SMEs can achieve BA and SM (Ghosh *et al.*, 2022; Al Jabri, Shaloh, Shakhoo, Haddoud, & Obeidat, 2024). By refining their sensing, seizing, and transforming capabilities, manufacturing SMEs can gain a competitive advantage in today's rapidly changing business environment. In various contexts, prior research has applied DC theory to SM (Garbellano and Da Veiga, 2019; Lin *et al.*, 2020; Savastano, Cucari, Dentale, & Ginsberg, 2022). For example, Lin *et al.* (2020) proposed a conceptual framework for SM that is facilitated by DC, which positively influence the

transformation of manufacturing firms. Likewise, the research conducted by [Savastano et al. \(2022\)](#) focused on identifying and empirically analyzing the DC that drive the development of digital manufacturing competencies. Despite the application of DC theory in SM, there remains a scarcity of research exploring the relationship between SM and BA, as well as the moderating effects of Industry 4.0 technologies such as MA and IoT.

*2.1.2 Technology-organisation-environment theory.* To enhance the application of DC, this study employs the Technology-Organisation-Environment (TOE) framework. The TOE framework provides a comprehensive insight into how organizations, particularly manufacturing SMEs, can achieve and sustain business agility (BA) and competitive advantage, particularly in environments characterized by rapid change and technological advancement ([Bhuiyan, 2024](#)). [Singh, Srivastava, Chaudhuri, Chatterjee, and Vrontis \(2024\)](#) highlight that the TOE framework contextualizes DC theory by considering the specific organizational, technological, and environmental factors that influence a manufacturing SME's ability to innovate and adapt. Beyond the DC of manufacturing SMEs, the TOE framework serves as a tool for evaluating the adoption of new technologies by factoring in the technological attributes and environmental limitations encountered by these organizations.

Despite the focus of DC theory on internal adaptation processes, the TOE framework enhances our understanding of how the competitive landscape and broader technological context affect and interact with DC ([Ghobakhloo & Ching, 2019](#); [Abdurrahman, Gustomo, & Prasetyo, 2024](#)). A more comprehensive understanding of how manufacturing SMEs achieve BA within specific technological contexts can be attained by integrating the internal focus of DC with the contextual perspective provided by TOE ([Hu and Zhang, 2025](#)). For example, a manufacturing SME may exhibit strong DC that enable it to identify and capitalize on opportunities in a rapidly evolving market. However, the dynamic attributes of manufacturing SMEs may not translate into successful innovation if the organizational capacity to assimilate that technology, along with the specific technological environment (such as the maturity of emerging technologies or the competitive intensity surrounding them), is not considered. The TOE framework partially addresses this gap by providing a more detailed understanding of the context in which DC are deployed ([Arifin, 2015](#); [Babu et al., 2024](#); [Vafaei-Zadeh, Nikbin, Danaraj, & Hanifah, 2025](#)). Previous studies have applied TOE theory in various domains, including the adoption of SM systems in SMEs ([Shukla & Shankar, 2022](#)), the influence of Industry 4.0 elements on BA ([Morawiec & Sołtysik-Piorunkiewicz, 2023](#)), and the readiness and adaptation of industries to the fourth industrial revolution ([Bhuiyan, 2024](#)). However, there is a lack of knowledge regarding the application of TOE in the context of manufacturing SMEs, particularly concerning the relationship between BA and SM. This research aims to utilize TOE as a complementary theoretical framework to bridge this gap.

## 2.2 Smart manufacturing in SMEs

SM is characterized as the digital transformation of the complete production system, utilizing big data analytics, flexible manufacturing techniques, artificial intelligence (AI), real-time control and monitoring, along with enhanced productivity ([Phuyal, Bista, & Bista, 2020](#)). [Zhang and Ming \(2019\)](#) assert that collaborative systems are employed in SM to achieve goals such as responsiveness, efficiency, and adaptability. This enhances coordination and communication, which are vital for effective teamwork within a production environment. Digital technologies in SM enable this capability. For instance, sensors and IoT devices provide robotic systems and human operators with real-time data, facilitating seamless communication and efficient operations ([Ghobakhloo & Ching, 2019](#); [Kurfess, Saldana, Saleeby, & Dezfouli, 2020](#)). [Yao et al. \(2019\)](#) assert that collaborative systems in SM can lead to increased automation, reduced material waste, improved product quality, and enhanced safety. By integrating digital technologies with human capabilities, SM can boost production and efficiency. A fundamental aspect of SM is manufacturing automation. By merging automation with advanced technologies such as IoT, AI, and data analytics, SM fosters the

development of more responsive, adaptable, and efficient production systems. While automation simplifies processes, SM leverages data to optimize and adjust them, ultimately enhancing productivity and agility (de Assis Dornelles, Ayala, & Frank, 2022; Wang, Zheng, Yin, Shih, & Wang, 2022; Zafar, Langás, & Sanfilippo, 2024). SM provides substantial advantages for SMEs by enhancing efficiency, productivity, and competitiveness through technologies such as AI and the IoT (Bhatia & Diaz-Elsayed, 2023). This approach enables SMEs to become more agile and competitive by improving quality control, facilitating greater customization, and boosting overall performance (Islam *et al.*, 2025). Moreover, SM optimizes operations via real-time data analysis, which results in improved planning and execution (Hu, 2025). According to Gao, Tan, and Chen (2025), SM can significantly reduce costs by enabling predictive maintenance, minimizing waste, and optimizing resource allocation. Technologies like digital twins facilitate virtual testing, conserving resources and accelerating the development of innovative products (Kumar & Channi, 2025). Additionally, it promotes sustainability by decreasing energy consumption and waste. Furthermore, cloud-based AI and other scalable solutions are rendering the adoption of these technologies more affordable and practical for SMEs, which previously were primarily accessible to large corporations (Chitra *et al.*, 2025).

However, there are inconsistencies in the existing literature concerning SM in SMEs, especially in relation to the appropriateness of current frameworks and the efficacy of specific implementation strategies. One perspective (Kasapoğlu, Yavuz, Dindarık, & Öztel, 2025; Jamwal, Agrawal, & Sharma, 2025; Kee, Cordova, & Khin, 2025; de Larmelina, da Silva, & Risso, 2025) posits that the existing readiness and maturity models fall short, as they were primarily developed for larger organizations and fail to consider the unique constraints faced by SMEs. Conversely, another viewpoint (Dwivedy, Pandit, & Khatler, 2025; Rana & Bhambri, 2025; Mogali, 2025) argues that the adoption of technologies such as AI is attainable for SMEs by utilizing cloud-based solutions and initiating a structured, scalable data strategy. The principal contention lies between the assertion that a fundamentally new approach is necessary due to the limitations inherent to SMEs (Alkhodair & Alkhudhayr, 2025; Kwak, Yoon, & Martí-Parreño, 2025; Rani, Mishra, Alshamrani, Alrasheedi, & Pamucar, 2025) and the opposing argument (Mittal *et al.*, 2020; Del Giudice *et al.*, 2021; Gašpar *et al.*, 2025) that existing tools can be modified for effective implementation. Dutta, Kumar, Sindhwani, and Singh (2022) indicate that overcoming these obstacles necessitates an emphasis on business outcomes, an appropriate implementation strategy, and the utilization of accessible solutions such as collaborative manufacturing systems (Zheng *et al.*, 2018; Tao *et al.*, 2022) and customer-data-driven manufacturing automation AI (Feng *et al.*, 2022; Jadhav, 2025) to render the advantages of SM more attainable for SMEs. To bridge the aforementioned literature gap, the current study investigates the implementation of SM within SMEs and its impact on the agility of SME businesses.

### 2.3 Business agility in SMEs

Business agility (BA), as defined by Saputra, Sasanti, Alamsjah, and Sadeli (2022), refers to an organisation's capacity to rapidly and effortlessly modify its operations and direction in response to highly unpredictable internal and external circumstances. Furthermore, Saputra *et al.* (2022) argue that BA can be applied at different organisational levels by reducing response times. This allows companies such as SMEs to capitalize on market positioning opportunities, reorganize or adjust their operations in a fluid environment, and enhance productivity and customization.

BA for SMEs in emerging economies pertains to their capacity to adjust to a fluid and frequently unstable environment by being adaptable, innovative, and responsive (Abrokwah-Larbi, 2024b; Quansah, Hartz, & Salipante, 2022). This ability is essential due to constrained resources and increased market volatility, necessitating a more entrepreneurial approach in marketing, operations, and strategy (Taghizadeh, Rahman, Nikbin, Radoska, & Maleki Far,

2024). Critical components involve enhancing technological and human capabilities (Satar, Musadieq, Hutahayan, & Solimun, 2025), cultivating a culture of adaptability (Shaikh, 2025), and strategically addressing both local and global changes to maintain competitiveness (Shi, 2024). Nevertheless, discrepancies in the literature regarding BA in SMEs from emerging economies highlight the conflict between agility (Sreenivasan & Suresh, 2024; Desalegn, Guedes, Da Silva Gomes, & Tebeka, 2024) and efficiency (Hwang & Kim, 2022) (where agility necessitates adaptability, while efficiency requires stability), the difficulty of achieving agility in light of resource limitations (Adhiatma, Fachrunnisa, & Nurhidayati and Rahayu, 2023) (as SMEs possess limited resources yet must remain agile), and the diverse interpretations of agility's effects (Haverila, Haverila, McLaughlin, Mohiuddin, & Su, 2025) (which can be bolstered by collaboration in certain contexts but obstructed by other factors such as weak institutions or particular market conditions).

However, contradictions in the literature concerning customer agility frequently arise from the conflict between flexibility and control, as well as the ongoing discussion regarding whether agility is fundamentally about customer-centric co-creation or strategic adaptation to market fluctuations. Some studies (Kaarti, Ojasalo, & Wait, 2025; Ford & Yoho, 2025) underscore the importance of customer-centricity through the prompt and ongoing delivery of valuable products, while others (Seow, Choong, Low, Ismail, & Choong, 2024; Musa & Enggarsyah, 2025) concentrate on a firm's capacity to modify its overall strategy and operations in a shifting environment, indicating a potential clash between addressing the immediate demands of the customer and the long-term objectives of the business.

Moreover, the literature on strategic agility in SMEs reveals contradictions, particularly regarding the tension between exploitation and exploration, as well as the necessity to balance stability with flexibility. Additional contradictions stem from the vagueness of the term "strategic agility" itself, and the difficulties associated with its measurement. Some studies (Adomako *et al.*, 2022; Dou & Ishaq, 2025) concentrate on metrics related to flexibility, such as speed and customization, while others highlight a more comprehensive meta-capability of adaptation. This divergence complicates the reconciliation of findings and the consistent operationalization of the concept. Furthermore, there exists a gap in comprehending how to integrate strategic agility with other concepts, such as business model innovation, particularly within the context of intelligent manufacturing. There is also a pressing need for a holistic understanding of the relationship between strategic and operational agility in SMEs. In addition, the literature on operational agility in SMEs presents contradictions, including the unclear and conflicting role of resource constraints, as well as the absence of a consensus regarding how various organizational capabilities, such as innovation or digital technologies, interact to foster agility. While certain research (Motwani & Katatria, 2024; Jaafar *et al.*, 2025) posits that agility necessitates flexibility, which may conflict with the rigid processes essential for efficiency, other studies (Abdelilah, El Korchi, & Balambo, 2018; Carvalho *et al.*, 2023) investigate how these two aspects can be effectively managed, underscoring the complexity and context-dependent nature of their relationship. Furthermore, although resource limitations frequently pose challenges for SMEs, the literature (Iqbal *et al.*, 2022; Camarinha-Matos, Rocha, & Graça, 2024; Sindakis, Showkat, & Showkat, 2025) indicates that specific capabilities and strategies, such as leveraging collaborative networks in SM, can alleviate these constraints and enhance agility. To bridge the literature gap, the current research examines how SM influences the BA of SMEs within the manufacturing industry.

#### 2.4 Internet of things in smart manufacturing context

According to De Cremer *et al.* (2017), the IoT constitutes a network of interconnected items, services, and systems that are integral to the current internet framework. The primary feature of the IoT is its ability to facilitate communication among objects and devices, thereby fostering a seamless integration between computer-based systems and the physical world. By collecting and analyzing data from sensors located at the endpoints of connected items, the IoT

can be utilized to monitor, evaluate, and develop “smart” devices that significantly enhance productivity (Soori, Arezoo, & Dastres, 2023). Onu *et al.* (2025) contend that the IoT acts as the foundational data flow mechanism in SM, enabling machines, sensors, and systems to interconnect and create a dynamic ecosystem. This connectivity allows SMEs to collect and analyze data in real time, thereby improving the scalability, accuracy, and efficiency of their manufacturing processes (Yang, Kumara, Bukkapatnam, & Tsung, 2019). Moreover, the IoT promotes data flow within the smart factories of SMEs by transforming raw data into actionable insights (Sahoo & Lo, 2022; Ali *et al.*, 2024; Qiu *et al.*, 2025). Abbasian Dehkordi *et al.* (2020) emphasize that data aggregation within the IoT is crucial for SM in SMEs, involving the collection, integration, and condensation of data from various sources, such as sensors and devices, to derive valuable insights and enhance productivity. This process enables real-time monitoring, anomaly detection, and optimization of manufacturing processes, ultimately leading to improved resource allocation and decision-making (Heidari, Shishehlou, Darbandi, Navimipour, & Yalcin, 2024). Therefore, data aggregation is vital for the implementation of IoT and SM in the context of SMEs, as it transforms raw data into actionable insights that enhance productivity, reduce costs, and improve overall performance (Sanyal & Zhang, 2018; Yousefi, Karimipour, & Derakhshan, 2021).

Nevertheless, the literature on IoT in SM presents contradictions, including differing opinions on the viability of complete automation compared to the need for human-centered models (Pugnaietto, 2025; Keshmiry & Hassani, 2025), the equilibrium between centralized cloud solutions and decentralized edge computing (Javadpour, Sangaiah, Zhang, Vidyarthi, & Ahmadi, 2024; Abughazalah, Alsaggaf, Saifuddin, & Sarhan, 2024), and the debate over whether the advantages of efficiency surpass the increasing security threats (Abdullahi & Lazarova-Molnar, 2025; Sebestyen, Popescu, & Zmaranda, 2025). While certain studies advocate for the efficiency and productivity improvements brought by IoT (Yang *et al.*, 2019; Javaid, Haleem, Singh, Rab, & Suman, 2021; Soldatos, Gusmeroli, Malo, & Di Orto, 2022), other research (Narwane, Raut, Gardas, Narkhede, & Awasthi, 2022; Krishnan, 2024; Modrak & Soltysova, 2025) underscores the considerable challenges associated with investment, workforce capabilities, and the intrinsic security risks of interconnected systems. Conversely, contradictions in the literature regarding IoT and SM for SMEs highlight the conflict between its extensive potential for efficiency (Mittal *et al.*, 2020; Jang, Chung, & Son, 2022; Alkhodair & Alkhudhayr, 2025) and the substantial practical hurdles that SMEs encounter during adoption (Peter, Pradhan, & Mbohwa, 2023; Abdulaziz *et al.*, 2023; Shah, Hussain Madni, Hashim, Ali, & Faheem, 2024). Some studies (Dutta *et al.*, 2022; Atieh *et al.*, 2023) point out advantages such as cost savings and enhanced accuracy, while others (Narwane *et al.*, 2022; Krishnan, 2024) emphasize the significant initial costs, complexities of integration, and the shortage of expertise as critical barriers. To bridge these gaps and contradictions in the literature, the present study investigates the role of IoT in SM in relation to achieving BA in SMEs.

### 2.5 Marketing analytics in smart manufacturing context

Wedel and Kannan (2016) characterize MA as the process of gathering, organizing, and evaluating descriptive, diagnostic, predictive, and prescriptive data to enhance the understanding of marketing performance, improve the efficacy of marketing control instruments, and strengthen businesses’ return on investment. Additionally, Wedel and Kannan (2016) argue that MA fulfills various functions by illustrating how marketing engages with other facets of corporate digitization, including intelligent manufacturing. According to Omar, Minoufekar, and Plapper (2019), SM utilizes MA to amalgamate data from production, supply chains, and customer feedback, thereby facilitating the creation and marketing of personalized and optimized products. By leveraging technologies such as Big Data, IoT, and AI, SME manufacturers are able to enhance product-market alignment, tailor marketing communications, and support sales initiatives by delivering real-time insights to research and

development (R&D) and production teams (Lazarova-Molnar *et al.*, 2019; Shahzad, Wang, Chen, Li, & Riaz, 2025). This data-centric methodology fosters a more agile and responsive business model capable of adjusting to market fluctuations and emerging opportunities (Tao *et al.*, 2018; Chinchorkar, 2022). SM gathers extensive data from sensors, machinery, and the supply chain, while MA utilizes these insights to inform R&D and production processes (Kozjek, Vrabič, Rihtaršič, Lavrač, & Butala, 2020).

Nevertheless, discrepancies in the existing literature regarding MA within the context of SM stem from conflicting evidence concerning the extent to which MA enhances BA (defined as the business's capacity to adapt to changes) and overall performance. Additionally, there is an ongoing discourse regarding the influence of culture and standardization in reconciling the divide between these two domains. Certain studies indicate a positive association between analytics and agility (Li, Khan, Ahmad, & Shahzad, 2022; Khan, Talukder, Islam, & Islam, 2024; Haverila *et al.*, 2025), whereas others (Turi, Khwaja, Tariq, & Hameed, 2023) report no significant correlation. The effectiveness of this interaction is significantly influenced by variables such as data quality, organizational culture, and the ability to convert insights into actionable outcomes. Furthermore, some research (Dutta *et al.*, 2022; Alkhodair & Alkhudhayr, 2025) contends that the existing evidence is inadequate to offer comprehensive guidance applicable to all manufacturing firms. In order to resolve these discrepancies and tensions within the literature, the present study investigates the role of MA in SM as it pertains to BA in SMEs.

### 3. Conceptual model and hypothesis development

A conceptual framework grounded in DC and TOE theories, alongside a comprehensive literature review on SM, IoT, MA, and business agility (BA), has been established to facilitate the empirical assessment of the influence of SM on business agility, with the moderating effects of IoT and MA. Within this framework, SM serves as the independent variable, business agility functions as the dependent variable, while IoT and MA act as the moderating variables. This conceptual framework is depicted in Figure 1. The development of hypotheses concerning the relationships among the variables (SM, BA, IoT, MA) within the conceptual framework is elaborated upon in the subsequent sections.

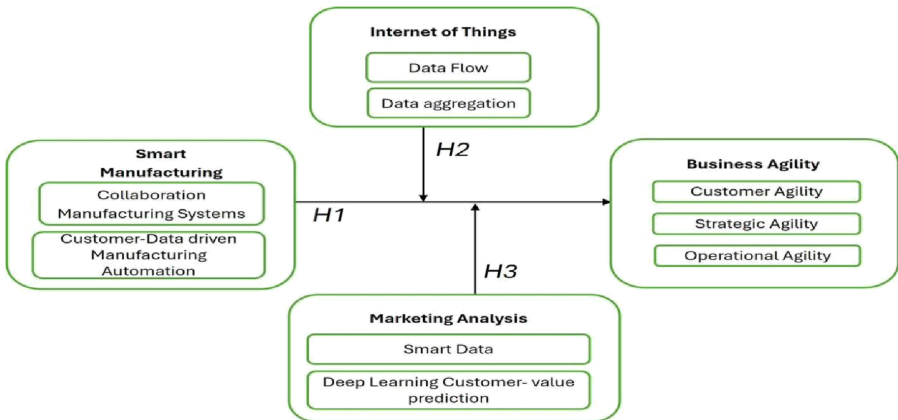


Figure 1. The impact of SM on BA and the moderating roles of IoT and MA. Source: Authors' own work

### 3.1 *The relationship between SM and business agility*

According to [Kang and Hew \(2025\)](#), SM improves BA by facilitating swift responses to market fluctuations, customization, and the exploration of new opportunities through technologies such as AI, automation, and IoT. This fosters a flexible, data-driven environment where manufacturers can rapidly adjust their processes, integrate their value chains, and meet customer demands, resulting in enhanced competitiveness and operational excellence ([Riaz & Ali, 2025](#)). [Tyagi, Mishra, Vedavathi, Kakulapati, and Sajidha \(2024\)](#) contend that SM employs advanced technologies like AI, robotics, and IoT to develop systems capable of swiftly reconfiguring production in response to unexpected market changes. It supports flexible production models that accommodate small batches, high product complexity, and mass customization, which traditional rigid assembly lines struggle to achieve ([Fernandez-Miguel et al., 2024](#)). By harnessing digitalization, SM enhances information sharing between an SME's internal systems and its partners, promoting greater agility throughout the entire value chain ([Aitzhanova, Dikhanbayeva, Turkyilmaz, & Shehab, 2024](#)). The capacity to capture and analyze real-time data from sensors and other interconnected systems enables more proactive and informed decision-making, allowing SMEs to seize opportunities or mitigate risks more effectively ([Sharma, Sharma, & Grover, 2024](#)). Agile production methods, facilitated by smart technologies, can reduce lead times by synchronizing production and logistics, thereby enabling on-demand production ([Ding, Ferras Hernandez, & Agell Jane, 2023](#)). Technologies such as additive digital molding pave the way for new business models, including direct manufacturing and home production, which provide companies like SMEs with increased flexibility and control over their operations and supply chains ([Johns, 2022](#); [Elhazmiri, Naveed, Naveed, & Ul, 2022](#); [Devito et al., 2024](#)).

Nevertheless, there are contradictions present in the existing literature regarding the connection between SM and BA, especially in terms of its universal advantages ([Bouchard et al., 2022](#); [Krishnan, 2024](#)) compared to possible adverse effects, as well as the varying impacts observed in different contexts such as SMEs and large enterprises ([Jung et al., 2015](#); [Fernandez-Miguel et al., 2024](#)). Certain studies ([Mohaghegh, Åhlström, & Blasi, 2024](#); [Xi, Liu, Fang, & Feng, 2024](#)) underscore the capacity of SM to bolster agility through DC, while other research ([Castiglione, Cimmino, Di Nardo, & Murino, 2024](#); [Bagherian, Srivastav, & Mukherjee, 2025](#)) points out the potential trade-offs between the efficiency offered by SM and the flexibility required for agility, particularly in relation to resource allocation and responsiveness. Moreover, the literature presents inconsistencies regarding the role of SM across various contexts, with some studies concentrating on large corporations and others indicating a necessity for further investigation into SMEs ([Jang et al., 2022](#); [Rani et al., 2025](#)). It is noted in the literature that while SM can enhance certain sustainability metrics (economic and environmental), it may adversely affect others (social, such as equality). This results in a contradiction where the drive for efficiency and agility through SM might compromise other significant business objectives ([Ghobakhloo, Mahdiraji, Iranmanesh, & Jafari-Sadeghi, 2024](#)). However, the effectiveness of SM is significantly influenced by the specific context of the SME, including its current capabilities and the volatility of its market environment ([Zhang et al., 2024](#)). SMEs aiming to capitalize on SM should first focus on enhancing their agility. This entails fostering a culture of innovation and adaptability, as well as developing digital capabilities that can be efficiently utilized within an agile framework ([Shin, Lee, Kim, & Rhim, 2015](#)). In light of the preceding literature discussion, the study posits the following hypothesis.

*H1. Smart manufacturing has a significant impact on business agility.*

### 3.2 *The moderating role of IoT on the relationship between SM and business agility*

The IoT serves as a facilitator that empowers SM to greatly enhance BA by delivering real-time data, fostering improved communication, and augmenting process control ([Vates,](#)

Sharma, Kanu, Gupta, & Singh, 2022; Annavarapu *et al.*, 2025). This indicates that the beneficial correlation between SM and BA is reinforced, as IoT provides the visibility and responsiveness essential for adapting to market fluctuations (Chinchorkar, 2023; Hu *et al.*, 2024). For instance, IoT-enabled supply chain tracking enables organizations to respond more swiftly to disruptions, a capability that is directly supported by the technology (Rath, Khang, & Roy, 2024). IoT strengthens the connection between SM and BA in SMEs, primarily by leveraging real-time data from interconnected devices to facilitate quicker and more informed manufacturing decision-making, predictive maintenance, and optimization of manufacturing processes (Kalsoom *et al.*, 2021; Bi, Jin, Maropoulos, Zhang, & Wang, 2023). This connectivity is vital for SMEs to address resource constraints and convert SM from a theoretical concept into a practical instrument for agility, enabling them to be more responsive to market dynamics, foster innovation, and enhance operational efficiency (Mhlongo, van der Poll, & Sethibe, 2023; Almeida & Okon, 2025). In the absence of IoT, SM capabilities such as automation may remain disjointed. However, IoT integrates these capabilities, allowing an SME not only to operate efficiently but also to swiftly reconfigure production, manage inventory in real-time, and respond to evolving customer demands in a synchronized manner (Ashima *et al.*, 2021; Hu *et al.*, 2024; Khan *et al.*, 2025). Ultimately, while SM lays the groundwork for establishing an agile organization, it is the IoT that supplies the requisite data, connectivity, and real-time intelligence to render that framework genuinely effective and responsive in achieving BA (Yang *et al.*, 2019; Kandarkar & Ravi, 2024; Pant, Singh, Gehlot, & Thakur, 2025).

Nevertheless, there are contradictions in the existing literature concerning the moderating influence of IoT on SM and BA. Some studies (Mrugalska & Ahmed, 2021; Vates *et al.*, 2022; Bego and Mattos, 2024) identify a positive correlation, whereas others (Alfaqiyah, Alzubi, Aljuhmani, & Öz, 2025; Qiu *et al.*, 2025) propose that the relationship is intricate and not consistently assured. For example, certain research (Roy, Schoenherr, & Jayaram, 2024; Pullagura *et al.*, 2025; Zahid, Leclaire, Hammadi, Roberta, & El Ballouti, 2025) indicates that IoT and other Industry 4.0 technologies can bolster agility by enhancing visibility and collaboration. Conversely, some studies argue that additional factors, such as the inherent organizational agility or the absence of essential infrastructure, may hinder this beneficial effect (Krishnan, 2024; Ali & Mahmood, 2024; Vafaei-Zadeh *et al.*, 2025). Moreover, certain studies suggest that specific digital technologies, including IoT, might exert a more pronounced influence on lean practices compared to agile methodologies, thereby adding complexity to the relationship (Anosike *et al.*, 2021; de Oliveira-Dias, Maqueira-Marín, Moyano-Fuentes, & Carvalho, 2023). On a different note, the recent research conducted by Alfaqiyah *et al.* (2025) argues that the simultaneous mediating and moderating roles of various Industry 4.0 technologies, such as IoT, on supply chain resilience and agility remain inadequately understood and empirically untested within the manufacturing domain. Wahab and Radmehr (2024) further emphasize the necessity for additional research into how the strategic alignment of digital capabilities (including IoT) with BA is vital for enhancing firm performance, as well as how IoT integrates into this dynamic. Thus, it is essential to examine how IoT collaborates with other technologies to realize a synergistic effect in SM and BA. For instance, the integration of IoT with MA can yield more robust capabilities in the synergy of SM and BA than relying on a single technology in isolation. Based on the preceding discussion of the literature, the study posits that.

H2. The relationship between smart manufacturing and business agility is significantly moderated by Internet-of-Things.

### 3.3 The moderating role of MA on the relationship between SM and business agility

MA serves as a facilitator, enhancing the connection between SM and BA by delivering the precise market insights necessary to convert SM capabilities into agile actions (Tao *et al.*,

2018; My, 2021; Tarn & Wang, 2023; Balaha, Albinali, Alrabiah, Ali, & Bahroun, 2025). SM lays the groundwork for agility through automation and connectivity, while MA offers the methodology by facilitating quicker sensing, planning, and responses to market fluctuations (Liu, Li, Tang, Lin, & Liu, 2019). This synergy enables SMEs to swiftly adjust production, customize products, and seize new opportunities highlighted by the analytics (Tang & Meng, 2021). SM produces extensive data via IoT, yet MA supplies specific tools and insights to decode this data within the framework of market dynamics. This empowers SMEs to detect market signals and opportunities with greater speed and precision (Agag *et al.*, 2024). By examining market trends and consumer behavior, MA allows SMEs to enhance their strategic planning and manufacturing choices. This guarantees that the capabilities of SM are focused on the most promising and agile opportunities (Hossain, Agnihotri, Rushan, Rahman, & Sumi, 2022). MA converts raw data into actionable insights, such as identifying which products to personalize, determining where to invest marketing resources, or enhancing customer experience. These insights are vital for SMEs to “activate” the potential agility of their SM systems (Vesterinen, Mero, & Skippari, 2024). MA can significantly improve the “dynamic capabilities” of SMEs, which refer to their ability to sense, seize, and reconfigure resources. In the context of SM, this capability allows SMEs to effectively capitalize on opportunities and adjust production in response to real-time market intelligence (Cao, Tian, & Blankson, 2022; Tu, 2025). For instance, a smart factory might swiftly alter its production lines; however, without data regarding shifting consumer preferences, such adjustments could be misguided (Li *et al.*, 2022; Kumar, Sangwan, Herrmann, & Thiede, 2025). Furthermore, MA can detect an increase in demand for personalized products (Aljumah, Nuseir, & Alam, 2021). Consequently, the smart factory can leverage its automated and interconnected systems to rapidly and efficiently adjust production to satisfy that demand, resulting in enhanced market responsiveness and BA (Kamel, 2023; Theodorakopoulos & Theodoropoulou, 2024).

Nevertheless, discrepancies are present in the existing literature concerning the moderating influence of MA on the relationship between SM and BA. This is largely because some research (Omar *et al.*, 2019; Tseng, Aghaali, & Hajli, 2022) indicates a positive moderating effect, while other studies (Haverila *et al.*, 2022, 2025) report a null or even negative correlation. The situation is further complicated by ongoing discussions regarding whether MA serves as a direct catalyst for agility (Riaz and Ali, 2025; Thanabalan, Vafaei-Zadeh, Hanifah, & Ramayah, 2025) or functions as a moderator (Wang, Song, & Zhang, 2025; Samadhiya, Naz, Kumar, Garza-Reyes, & Luthra, 2025) that enhances the connection between SM capabilities and agility. Furthermore, the efficacy of MA is a subject of contention, with certain studies (Gunasekaran, Yusuf, Adeleye, & Papadopoulos, 2018; Awan *et al.*, 2022; Vesterinen *et al.*, 2024) demonstrating its beneficial effects on agility, while others (Babalghaith & Aljarallah, 2024; Haverila *et al.*, 2025) propose that it may exert a neutral influence due to variables such as data quality, talent shortages, and security risk concerns. Nonetheless, the true value of MA resides in the ability of SMEs to convert data into actionable insights and incorporate these insights into their organizational processes. This conversion is what enables the translation of SM into BA (Mosbah, Ali, & Tahir, 2023). Considering the preceding discussion in the literature, this study posits the following hypothesis.

- H3. The relationship between smart manufacturing and business agility is significantly moderated by marketing analytics.

## 4. Methodology

### 4.1 Data collection procedure and sample

The population for this study consists of owners and managers from 626 manufacturing small and medium-sized enterprises (SMEs) located in the Eastern Region of Ghana, all of whom are registered members of the GEA. This region is notable for having the highest proportion of workers employed by SMEs in Ghana, which is the reason why manufacturing SME operators

from this area were selected for the research (Chun, 2008; Ghana Statistical Service, 2006). The selected manufacturing SMEs have been operational for at least two years. To determine the sample size, the Yamane's formula was applied:  $n = N/[1 + N(e)^2]$ , where  $n$  represents the sample size of the study;  $N$  is the population size, which is 626;  $e$  denotes the margin of error (5%); and 1 is a constant. Consequently,  $n = 626/[1 + 626(0.05)^2] = 244$ . Twelve sub-populations or strata were established from the finite population of manufacturing SMEs through a stratified random sampling technique. These strata were formed based on shared characteristics among the manufacturing SMEs. Subsequently, each stratum or sub-population underwent a simple random sampling process. The purpose of stratification is to ensure that the sample encompasses representatives from each manufacturing SME stratum. The statistical theory supporting stratified sampling indicates that, especially in scenarios where significant differences exist among subgroups, stratified sampling yields more precise estimates than simple random sampling when a population is segmented into homogeneous subgroups and then randomly sampled within those groups (Glasgow, 2005; Mukherjee, 2023).

Consequently, the sample size for each stratum or sub-population was determined using the following formula:  $n_h = N_h/(\sum N \times n)$ , where  $n_h$  represents the number of manufacturing SMEs needed from each stratum/sub-population;  $N_h$  denotes the total number of manufacturing SMEs within each stratum/sub-population;  $n$  indicates the sample size of manufacturing SMEs, which is 244; and  $\sum N$  signifies the overall population size, totaling 626. Therefore, a simple random sampling method was employed to select the population within each stratum after categorizing the SME manufacturing population in the Eastern Region of Ghana into strata (sub-populations). Consequently, the number of manufacturing SMEs that the questionnaire should focus on in each stratum is as follows: cooking oil manufacturing SMEs ( $n_h = 16$ ); dress manufacturing SMEs ( $n_h = 26$ ); pottery manufacturing SMEs ( $n_h = 12$ ); cosmetics manufacturing SMEs ( $n_h = 15$ ); beads manufacturing SMEs ( $n_h = 26$ ); shoe manufacturing SMEs ( $n_h = 22$ ); furniture manufacturing SMEs ( $n_h = 25$ ); dietary supplement manufacturing SMEs ( $n_h = 16$ ); soap manufacturing SMEs ( $n_h = 21$ ); ice cream manufacturing SMEs ( $n_h = 12$ ); pepper sauce manufacturing SMEs ( $n_h = 13$ ); and bread and pastries manufacturing SMEs ( $n_h = 40$ ). All scale items utilized in this research were rated on a five-point Likert scale, ranging from strongly disagree (1) to strongly agree (5).

Utilizing a Google Form, questionnaires were distributed to the managers or owners of the manufacturing SMEs included in the sample. The limitations of Google Forms regarding quantitative data collection involve sampling bias, as self-selected online respondents may not accurately represent the target population. Furthermore, restricted internet access among participants can result in a non-representative sample. Additional drawbacks consist of basic design options, potential security and privacy concerns, a lack of advanced logic features, and dependence on internet connectivity. Nevertheless, in this study, follow-up with participants was also conducted through phone calls and in-person visits. Respondents were made aware of the primary objective of the study and were guaranteed confidentiality and anonymity. This approach mitigated social desirability bias and encouraged more honest responses. A total of 244 questionnaire sets were disseminated in the present study, with 237 sets successfully retrieved, resulting in a response rate of 97.1%. As a result, after data administration and cleaning, 227 sets of valid responses to the questionnaires were selected for analysis, which was performed using the statistical software STATA 16.1.

#### 4.2 Construct measurement

The scales utilized in this study were constructed based on previous research findings. These scales have undergone modifications to align more closely with the present context and objectives of the current investigation. The five-item scale employed for measuring "smart manufacturing (SM)" was derived from the works of Mittal *et al.* (2019), Phuyal *et al.* (2020), and Jang *et al.* (2022). Additionally, a five-item scale was created to evaluate the "Internet-of-Things (IoT)" based on the research conducted by Ryalat, ElMoaqet, and AlFaouri (2023),

Soori *et al.* (2023), and Li, Zhang, Huang, Tian, and Sang (2023). The measure for “Marketing analytics (MA)” utilized a six-item scale adapted from the studies of Wedel and Kannan (2016), Tao *et al.* (2018), and Ren *et al.* (2019). Moreover, a four-item scale, modified from the research of Saputra *et al.* (2022) and Yusuf *et al.* (2023), was employed to assess “Business agility (BA).”

#### 4.3 Data analysis

In this research, Microsoft Excel was employed to code the data collected from the finalized and validated questionnaire. Once the data were coded, they were imported into the statistical software STATA 16.1 for use in a confirmatory factor analysis. This process facilitated the generation of descriptive statistics and the assessment of the validity and reliability (including Cronbach’s alpha, composite reliability, convergent and discriminant validity) of the items associated with the constructs of SM, IoT, MA, and business agility (BA). By utilizing the structural equation modeling (SEM) – path analysis technique, a multiple regression model was developed to evaluate hypotheses concerning the relationship between SM and BA, along with the moderating influences of IoT and MA on the connection between SM and BA. The application of Structural Equation Modelling (SEM) in this research is justified as it allows for the examination of complex theoretical models, supports the simultaneous evaluation of multiple relationships, accommodates unobserved or latent variables, and addresses measurement error. Unlike simpler methods such as basic regression, SEM provides a more comprehensive analysis by integrating direct, indirect, and reciprocal effects within a single model, thus offering more accurate and reliable insights into intricate variable systems. In this study, the independent variable is SM (SM<sub>i</sub>), the dependent variable is BA<sub>i</sub>, and the moderating variables are IoT (IoT<sub>i</sub>) and MA (MA<sub>i</sub>). Therefore, the following illustrates the regression relationship for the research model:

$$SM_i = \beta_0 + \beta_1 BA_i + \mu \quad (1)$$

$$SM_i * IoT_i = \beta_0 + \beta_2 BA_i + \mu \quad (2)$$

$$SM_i * MA_i = \beta_0 + \beta_3 BA_i + \mu \quad (3)$$

## 5. Results

### 5.1 Demographic distribution of respondents

The demographic distribution of the respondents is illustrated in Table 1. The demographic data provided by the participants of the research study encompassed their age categories, educational attainment, ownership types of SMEs, and the length of time their enterprises have been operational. As per the demographic analysis of the respondents, 39% identify as female and 56% as male. Additionally, within this study, the highest level of education attained is tertiary education at 54%, followed by secondary education at 24%. In terms of the distribution of ownership structures among the respondents, partnerships were the most prevalent at 20%, while sole proprietorships represented the largest share at 63%. Finally, regarding the duration of enterprise operation, a significant majority of respondents (67%) have been operating for over two years, whereas 27% have been in operation for exactly two years.

### 5.2 Construct reliability and validity

The variables or constructs of the research model (i.e. SM, IoT, MA, and BA), as outlined in Table 2, all exhibited KMO values exceeding the 0.7 threshold. Consequently, the constructs met the sample adequacy criteria necessary for confirmatory factor analysis. Similarly, it was observed that all factor loadings associated with the constructs of the study model surpassed the 0.7 threshold value. Thus, a significant relationship between the factors of the research

**Table 1.** Demographic distribution of participants

Characteristics	Level	Frequency	Percentages
Sex	Female	94	39%
	Male	136	56%
	Prefer not to answer	14	6%
Age group	8–24	43	18%
	25–34	125	51%
	35–44	51	21%
	45–54	11	5%
	55 and above	7	3%
	Prefer not to answer	7	3%
Educational level	No formal education	10	4%
	Postgraduate education	22	9%
	Primary education	16	7%
	Secondary education	58	24%
	Tertiary education	131	54%
	Prefer not to answer	7	3%
Ownership structure	Limited liability	29	12%
	Partnership	48	20%
	Sole proprietorship	154	63%
	Prefer not to answer	13	5%
Duration of enterprise operation	More than two years	164	67%
	Two years	66	27%
	Prefer not to answer	14	6%
<i>Total participants</i>		244	
<b>Source(s):</b> Authors' own work			

**Table 2.** Factor analysis, reliability and validity of Constructs (SM, BA, IoT, MA)

Factors	Items	Factor loading	Cronbach	KMO	Composite reliability	Average factor loading*	AVE**	Corr mat sqr
Smart Manufacturing (SM)	SM1	0.81	0.84	0.83	0.89	0.78	0.62	0.019
	SM2	0.85						
	SM3	0.77						
	SM4	0.72						
	SM5	0.77						
Internet of Things (IoT)	IoT6	0.81	0.89	0.88	0.92	0.84	0.72	0.004
	IoT7	0.83						
	IoT8	0.86						
	IoT9	0.84						
	IoT10	0.85						
Marketing Analytics (MA)	MA11	0.72	0.85	0.86	0.89	0.75	0.58	0.01
	MA12	0.77						
	MA13	0.80						
	MA14	0.74						
	MA15	0.79						
	MA16	0.68						
Business Agility (BA)	BA17	0.76	0.75	0.74	0.84	0.75	0.57	0.16
	BA18	0.77						
	BA19	0.78						
	BA20	0.71						

**Note(s):** \*Average factor loading >0.7, convergent validity established

\*\*Average Variance Extracted (AVE) > Correlation matrix squared; discriminant validity established

**Source(s):** Authors' own work

model and the items is indicated by a factor loading greater than 0.7 (refer to [Tables 2 and 4](#)). The components within the model employed in this research demonstrated Cronbach's alpha values that were above the 0.7 cutoff. This implies that the items developed or utilized for this study are suitable for their intended purpose and exhibit a high degree of internal consistency (see [Tables 2 and 4](#)). Furthermore, the composite reliability was evaluated to measure the internal consistency of the indicator variables loading onto the latent variable. Each component of the study model achieved a composite reliability value exceeding the 0.7 cutoff, indicating the presence of shared variance among the indicator variables loading on the latent variable ([Tables 2 and 4](#)). The average factor loading (AFL) of the factors in this study was determined to be greater than the 0.7 threshold ( $AFL > 0.7$ ), thereby confirming the convergent validity of the factors ([Table 2](#); [Fornell & Larcker, 1981](#)). As summarized in [Table 2](#), the average variance extracted (AVE) values for the factors in this study's model were found to exceed their corresponding squared correlation matrix (CMS) (i.e.  $AVE > CMS$ ), thus establishing the discriminant validity of the factors.

### 5.3 Regression analysis and hypotheses tests

The current study includes three main associations. The first association is explained by SM and BA; the second association is explained by SM and BA, with IoT acting as a moderator; and the third association is explained by SM and BA, moderated by MA. The three associations in this study were analyzed using SEM. [Hypothesis 1](#) was corroborated by the findings of the initial association, which revealed a positive and significant correlation between SM and business agility (BA) ( $\beta = 0.47, p < 0.001$ ) (refer to [Table 3](#)). Furthermore, this research indicated that within manufacturing SMEs, SM significantly enhances the effect of business agility (BA) by 47% ( $\beta = 0.47$ ). Consequently, SM emerges as a vital strategy influencing the capacity of manufacturing SMEs for business agility. All five items related to SM demonstrated a significant effect on BA; specifically, SM1 and SM2 exhibited the highest loadings, at 0.81 and 0.82, respectively (see [Tables 3 and 4](#)). The findings of the second association validated [Hypothesis 2](#), as they indicated a significant and positive relationship ( $\beta = 0.18, p < 0.001$ ) regarding the moderating effect of IoT on the relationship between SM and BA (refer to [Table 3](#)). The results of this research revealed that among manufacturing SMEs, the moderating effect of IoT substantially amplifies the relationship between SM and BA by 18% ( $\beta = 0.18$ ). Therefore, within manufacturing SMEs, IoT is identified as a critical element that moderates the interaction between SM and BA. All five items related to IoT were found to exert a moderating influence on the relationship between SM and BA; IoT8 and IoT10, with factor loadings of 0.86 and 0.85, respectively, were determined to have a significant impact ([Tables 3 and 4](#)).

Finally, the findings from the third association also corroborated [H3](#) (refer to [Table 3](#)) by revealing a positive and statistically significant relationship between the connection of SM and BA, as well as the moderating effect of MA ( $\beta = 0.26, p < 0.001$ ). Consequently, this study

**Table 3.** SEM regression table of the impact of SM on BA and the moderating roles of IoT and MA

Independent variables	BA Standardised coefficients beta ( $\beta$ )	95% CI	Standard error	z	p-value
SM	0.47	0.33–0.63	0.075	6.33	<0.001
SM*IoT	0.18	0.06–0.30	0.06	3.04	<0.002
SM*MA	0.26	0.15–0.36	0.05	4.64	<0.001

**Note(s):** \* $p$ -value <0.10, \*\* $p$ -value <0.05, \*\*\* $p$ -value <0.001

**Source(s):** Authors' own work

**Table 4.** Measurement of items for SM, IoT, MA, and BA

Factors	Code	Items	Median (IQR) response	KMO	Cronbach alpha
Smart Manufacturing (SM)	SM1	Is the manufacturing operation of my company data-driven?	4 (3–4)	0.9244	0.9183
	SM2	Data-driven manufacturing at my company enables precise and adaptable production of goods or services?	4 (3–4)	0.907	0.9169
	SM3	The data-driven manufacturing method used by my company enables us to react promptly to market change?	3.5 (3–4)	0.8856	0.9202
	SM4	My company has enhanced its manufacturing process since using a data-driven manufacturing system?	4 (3–4)	0.8377	0.9215
	SM5	Are the policies at my company supportive of data-driven manufacturing?	4 (3–4)	0.8162	0.9208
Internet of Things (IoT)	IoT6	My company supports internet use for market insight by using devices (such as laptops, tablets, and smart phones)?	4 (3–5)	0.933	0.9182
	IoT7	To get information about customer preferences for products or services, my company uses the internet?	4 (3–4)	0.9298	0.9161
	IoT8	My company uses the internet and devices (such computers, tablets, and smart phones) to share and exchange marketing data?	4 (3–5)	0.9073	0.9167
	IoT9	To boost our operational productivity and efficiency, my company uses the internet and devices (such as laptops, tablets, and smart phones)?	4 (3–4)	0.9155	0.9162
	IoT10	My company uses the internet and devices (such computers, tablets, and smartphones) to create products and services that meet customer expectations?	4 (3–4)	0.9062	0.917
Marketing Analytics (MA)	MA11	To understand marketing performance, can my company gather and analyse marketing data?	4 (3–4)	0.934	0.9177
	MA12	To create products and services that meet customer expectations, my company analyses marketing data?	4 (4–4)	0.9237	0.9176
	MA13	My company uses analysed marketing data to develop closer ties with its customers	4 (4–5)	0.9376	0.9165
	MA14	My business employs analysed marketing data to better understand the state of the market?	4 (3–4)	0.9078	0.9177
	MA15	Is the information assessed from marketing data used to inform my company's manufacturing decision?	4 (3–4)	0.8901	0.9169
	MA16	Can my company adapt to both anticipated and unforeseen changes in the marketplace?	4 (3–4)	0.8863	0.9198
	MA17	My company has the ability to seek potential opportunities using customer value predictions?	4 (4–5)	0.9012	0.9191

*(continued)*

**Table 4.** Continued

Factors	Code	Items	Median (IQR) response	KMO	Cronbach alpha
Business Agility (BA)	BA18	My company responds to customer requests with quickness?	4 (4–5)	0.8879	0.9203
	BA19	The resources currently available to my company allow us to quickly detect any changes in customer expectations?	4 (3–4)	0.917	0.9187
	BA20	My company can modify the features of its products and services at no extra cost to satisfy customer needs?	4 (3–4)	0.8425	0.9224

**Source(s):** Authors' own work

established that within manufacturing SMEs, the moderating effect of MA significantly enhances the relationship between SM and BA by 26% ( $\beta = 0.26$ ). Thus, in the context of manufacturing SMEs, MA emerges as a vital strategy that moderates the relationship between SM and BA. The relationship between SM and BA was shown to be influenced by all six components of MA, with MA13 and MA15 exerting the greatest impact, evidenced by factor loadings of 0.80 and 0.79, respectively (see [Tables 3 and 4](#)).

#### 5.4 SEM goodness-of-fit analysis

The root mean squared error of approximation (RMSEA) for the structural equation modeling (SEM) statistics, as detailed in [Table 5](#), was recorded at 0.099. According to the parsimony adjusted fit indices, this figure is considered acceptable, falling within the range of 0.08 to 0.1 ([MacCallum, Browne, & Sugawara, 1996](#)). The lower bound of the 90% confidence interval (CI) for the study model was established at 0.089, which is relatively close to the desired threshold of 0.05 ([Byrne, 2001](#)). Moreover, it was indicated that the upper bound of the 90% CI was 0.109, which is adjacent to the 0.1 criterion ([Hu & Bentler, 1999](#)). Additionally, the pclose value was found to be below the critical threshold of 0.05 (pclose < 0.001), or less than 0.001

**Table 5.** Goodness-of-fit for SEM (using STATA 16.1)

Fit statistic	Value	Description
<i>Population error</i>		
RMSEA	0.099	Root mean squared error of approximation
90% CI, lower bound	0.089	
upper bound	0.109	
pclose	<0.001	
<i>Information criteria</i>		
AIC	9726.34	Akaike's information criterion
BIC	9935.08	Bayesian information criterion
<i>Baseline comparison</i>		
CFI	0.84	Comparative fit index
TLI	0.81	Tucker-Lewis index
<i>Size of residuals</i>		
SRMR	0.208	Standardized root mean squared residual
CD	0.997	Coefficient of determination

**Source(s):** Authors' own work

(Brown & Cudeck, 1993). Therefore, the population error indices of the SEM model in this study, which encompassed RMSEA, the upper and lower bounds of the 90% CI, and pclose, were considered to indicate a satisfactory model fit (MacCallum *et al.*, 1996; refer to Table 5 and Figure 2). In comparison, the evaluation of baseline comparisons indicates that the Tucker-Lewis index (TLI) is 0.81 and the comparative fit index (CFI) was 0.84, both of which are close to the recommended value of 1 (Bentler, 1992). Consequently, it was concluded that the baseline comparison indices, which assessed the SEM model in this study and included CFI and TLI, represented a reasonable fit. Furthermore, the assessment of residual size revealed that the coefficient of determination (CD) was measured at 0.997, which is also near the threshold value of 1, while the standardized root mean squared residual (SRMR) was found to be 0.208, which is close to the suggested value of 0.00 (Jaccard & Wan, 1996). As a result, it was determined that the residual indices, including SRMR and CD, which evaluated the SEM model in this study, indicated a reasonable fit (see Table 5 and Figure 2).

**6. Discussion**

This research addresses the recent demand for quantitative investigations into the influence of SM on business agility (BA), as well as the moderating effects of Industry 4.0 technologies, including IoT and MA, within the framework of manufacturing SMEs in an emerging economy (Bortoluzzi *et al.*, 2022; Arcidiacono & Schupp, 2024; Jaafar *et al.*, 2025). The findings of the study reveal that SM positively affects the BA of manufacturing SMEs, aligning with earlier research (Jung *et al.*, 2015; Bouchard *et al.*, 2022; see Table 6). The results indicate that SM significantly enhances business agility by incorporating advanced technologies to develop more responsive, flexible, and data-driven production processes.

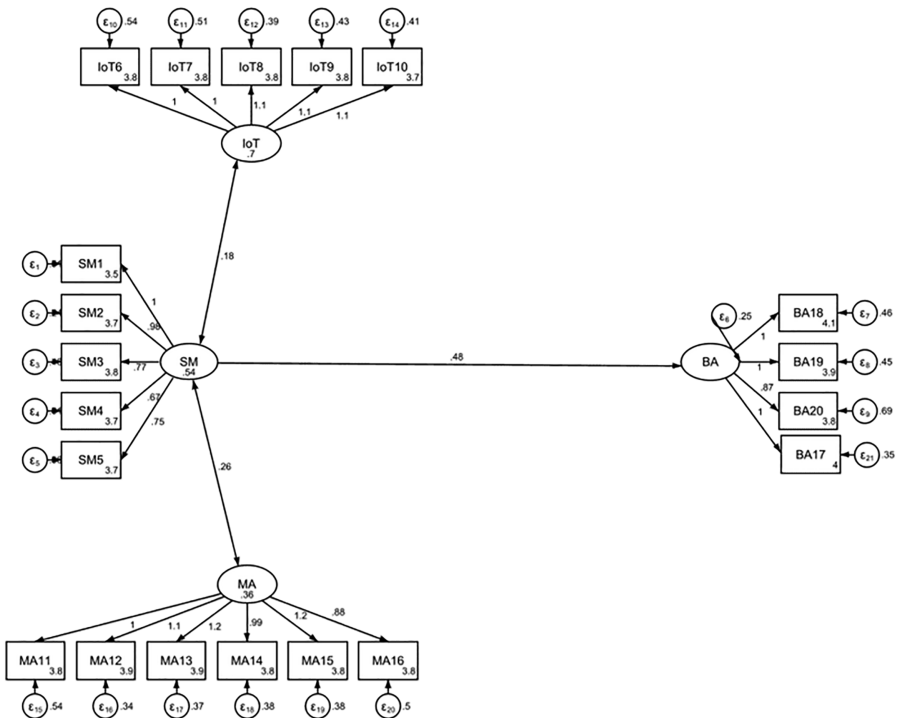


Figure 2. SEM model assessment result using STATA 16.1. Source: Authors' own work

**Table 6.** SEM model assessment results and summary results of hypothesis test

Hypothesis	Construct structural relationships	Path coefficient ( $\beta$ )	p-values	Decision
H1	SM $\rightarrow$ BA	0.47	<0.001	Supported
H2	SM * IoT $\rightarrow$ BA	0.18	<0.002	Supported
H3	SM * MA $\rightarrow$ BA	0.26	<0.001	Supported

*Summary results of hypothesis test*

Hypothesis	Outcome
H1: SM has a significant positive impact on BA	Supported
H2: The association between SM and BA is significantly moderated positively by IoT	Supported
H3: The association between SM and BA is significantly moderated positively by MA	Supported

**Source(s):** Authors' own work

For manufacturing SMEs, which frequently face resource limitations, this advancement results in quicker decision-making, improved customer responsiveness, and increased competitiveness. Furthermore, the findings illustrate a positive moderating influence of IoT on the relationship between SM and BA, corroborating previous studies such as [Vates et al. \(2022\)](#), [Bego and Mattos \(2024\)](#) (see [Table 6](#)). This result implies that IoT plays a crucial role in enhancing the BA of SMEs by revolutionizing SM practices. By supplying real-time data, facilitating automation, and improving connectivity, IoT empowers SMEs to function more efficiently, swiftly adapt to market demands, and compete more effectively with larger corporations.

Moreover, the research findings indicate that the moderating influence of MA on the connection between SM and BA is both significant and positive (refer to [Table 6](#)). This result aligns with earlier studies conducted by [Cao, Duan, and El Banna \(2019\)](#), [Rahman, Hossain, and Abdel Fattah \(2022\)](#), [Hossain et al. \(2022\)](#), [Liang, Li, Zhang, Nolan, and Chen \(2022\)](#), and [Abrokwah-Larbi \(2024a\)](#). The results imply that MA serves as a bridge between SM and BA for SMEs by facilitating data-driven decision-making that transforms customer and market insights into agile, optimized manufacturing processes. Rather than depending exclusively on intuition, SMEs can leverage real-time marketing data to synchronize production with genuine market demand and customer requirements, thereby enhancing their adaptability and competitive edge.

The findings of the present study further substantiate the theories of DC and Technology-Organization-Environment (TOE). From a DC perspective, the concepts of SM and BA are contingent upon the adoption of Industry 4.0 technologies, including IoT and MA. These technologies facilitate the creation of intelligent, interconnected systems that can respond to evolving consumer preferences and production demands, thereby enhancing BA. The relationship between BA, SM, and Industry 4.0 technologies such as IoT and MA is significant, as they empower production processes to identify, comprehend, and adapt to changes. The current research indicates that SM, IoT, and MA are crucial for the BA of manufacturing SMEs from a DC standpoint. This aligns with prior studies conducted by [Garbellano and Da Veiga \(2019\)](#) and [Savastano et al. \(2022\)](#). Furthermore, the results of this study highlight the evolution of an organizational culture that prioritizes data-driven decision-making over intuition, facilitated by the integration of IoT and MA to establish an optimal SM ecosystem that fosters BA. This finding is consistent with earlier investigations into the application of TOE in SM and the readiness and adaptation to Industry 4.0 within the manufacturing industry, as reported by [Shukla and Shankar \(2022\)](#) and [Morawiec and Sołtysik-Piorunkiewicz \(2023\)](#).

### 6.1 Theoretical implications

The topic of SM and its influence on business agility (BA) remains in the early stages of academic exploration, particularly within the SME sector. Consequently, it is essential to further examine the various dimensions, characteristics, and pace of development associated with SM. This research addresses previous calls for ongoing empirical investigations into the implications of SM on BA in the SME context (Kang & Hew, 2025; Alokshet al., 2025). The theoretical framework is depicted in Figure 1, which demonstrates the moderating roles of IoT and MA in the connection between SM and BA. Thus, the interplay between SM and BA is contingent upon the ongoing integration of IoT and MA, which facilitates the execution and improvement of context-oriented manufacturing strategies. To optimize BA enabled by SM, it is crucial for manufacturing SMEs to cultivate DC and a technological environment that promotes a knowledge-based culture and internal structures conducive to the interaction between SM and BA, alongside the moderating influences of IoT and MA. The DC and TOE theories provided the basis for the theoretical framework and the research hypotheses formulated for this study. This research clarifies how the DC and TOE theories elucidate the constructs and their interrelations within the theoretical framework. Furthermore, this study contributes to the existing literature by highlighting how a data and knowledge-driven approach to manufacturing can serve as a vital factor for BA in the SME context. Considering the moderating effects of IoT and MA, the development of contextual manufacturing insights represents the initial step toward achieving BA enabled by SM.

### 6.2 Practical implications for industry professionals

From the perspective of practitioners, this study illuminates the extent to which SM can aid manufacturing SMEs in achieving BA through the implementation of Industry 4.0 technologies such as MA and IoT. The empirical analysis highlights the role of IoT and MA in enabling manufacturing SMEs to attain BA via SM. Nevertheless, owners and managers of manufacturing SMEs must be ready to invest in various Industry 4.0 technologies to realize the expected returns in BA. Furthermore, technology investments should align with the strategic objectives of manufacturing SMEs, alongside careful planning that considers potential challenges and obstacles during the implementation phase. The simultaneous adoption of these technologies can yield dual advantages. On one hand, their implementation can enhance and expand offerings to better satisfy customer demands. On the other hand, the interactions among these technologies can provide data sources that can be strategically analyzed to improve production and products, as well as to deliver contextual and customized offerings. This could expedite the transformation of the business model, enabling manufacturing SMEs to operate in a sustainable ‘on demand’ manner over the long term. From this perspective, managers and owners of manufacturing SMEs can fully leverage IoT and MA by integrating technologies that facilitate the transition to SM. However, to mitigate the risk of failure, the current study recommends that manufacturing SMEs verify in advance that they possess the necessary resources and capabilities to effectively restructure both internal and external processes, as well as, if needed, the relationships within the value chain. To tackle issues related to adoption and readiness and to achieve BA driven by SM, prior evaluation and planning are essential, given that SM, IoT, and MA are all processes that demand significant resources and skills.

### 6.3 Policy implications

From the perspective of policymakers, SMEs in manufacturing can improve their technological capabilities for the adoption and implementation of SM, IoT, and MA through programs that provide financial and tax incentives. To effectively achieve their manufacturing transformation, SMEs that integrate IoT, MA, and SM may require specific resources and expertise. For example, they may need to acquire skills in the use of MA tools (such as web and social media analytics) and IoT tools (including smart devices, platforms,

and software for enhanced integration). In response, policymakers should consider establishing supportive technological ecosystems for manufacturing SMEs. These ecosystems ought to comprise a combination of digital technologies, infrastructure, and resources that enable these enterprises to adopt and integrate innovative technologies, thus enhancing their efficiency and competitiveness. Key elements include funding for experimentation, collaborative platforms that facilitate knowledge sharing and skill enhancement, and access to digital innovation hubs.

#### 6.4 Limitations and future research directions

The constraints of the present study provide opportunities for additional research. Firstly, the sample is comprised of manufacturing SMEs predominantly situated in the Eastern Region of Ghana. Consequently, the sample is limited to a single country and a specific geographic area. A one-nation sample is a frequent limitation in business research; however, to validate the cross-country applicability of the study's results, subsequent research could explore this subject across enterprises located in various emerging markets. Secondly, most of the manufacturing SMEs approached for this study were engaged in business-to-consumer activities. Future investigations should also encompass other contexts, such as business-to-business companies or different manufacturing sectors that are less acquainted with SM. Moreover, the current study employed quantitative research methodologies; nevertheless, future inquiries might adopt qualitative or mixed method approaches to gain a deeper understanding of the context, phenomena, and experiences related to SM and its impact on BA.

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