ADOPTING SMART MANUFACTURING: SPECIFIC NEEDS AND CHALLENGES OF SMALL, MEDIUM, AND MICRO ENTERPRISES (SMMES)

K.A. Bello[1*], M.G. Kanakana-Katumba[2] & R.W. Maladzhi[3]

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Contact details
* Corresponding author
kazeemb@dut.ac.za

Author affiliations
1 Department of Mechanical Engineering, Durban University of Technology, South Africa

2 Faculty of Engineering and the Built Environment, Tshwane University of Technology, South Africa

3 Department of Mechanical Engineering, Durban University of Technology, South Africa

ORCID® identifiers
K.A. Bello
https://orcid.org/0000-0003-2543-2590

M.G. Kanakana-Katumba
https://orcid.org/0000-0001-7475-2131

R.W. Maladzhi
https://orcid.org/0000-0003-3773-8538

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ABSTRACT

Smart manufacturing (SM) promotes a company’s key performance indicators (KPI) and provides a competitive advantage for business owners who successfully adopt it. This paper aims to evaluate the current conditions of South Africa small, medium, and micro enterprises (SMMEs), their frameworks, specific requirements, and problems. To achieve the goal of this study, a literature review was conducted to identify research gaps that needed to be addressed in order to support SMMEs successfully in their progress towards the adoption of SM. The results show that no specific SM frameworks are available to reflect the specific requirements and challenges of SMMEs. This study provides insights that would aid in developing realistic SM adoption requirements for SMMEs that precisely reflect their business realities. SMME stakeholders could clearly define their SM-specific goals with the assistance of an SM framework that is specifically tailored to support their needs.

OPSOMMING

Slim vervaardiging (SM) bevorder 'n maatskappy se sleutelprestasie-aanwysers (KPI) en bied 'n mededingende voordeel vir sake-eienaars wat dit suksesvol aanneem. Hierdie artikel het ten doel om die huidige toestande van Suid-Afrika klein-, medium- en mikro-ondernemings (KMMO's), hul raamwerke, spesifieke vereistes en uitdagings te evalueer. Om die doel van hierdie studie te bereik, is 'n literatuuroorsig gedoen om navorsingsgapings te identifiseer wat aangespreek moet word om KMMO's suksesvol te ondersteun in hul vordering na die aanvaarding van SM. Die resultate toon dat geen spesifieke SM-raamwerke beskikbaar is om die spesifieke vereistes en uitdagings van KMMO's te weerspieël nie. Hierdie studie verskaf insigte wat sal help met die ontwikkeling van realistiese SM-aannemingsvereistes vir KMMO's wat hul besigheidsrealiteite presies weerspieël. KMMO-belanghebbendes kan hul SM-spesifieke doelwitte duidelik definieer met behulp van 'n SM-raamwerk wat spesifiek aangepas is om hul behoeftes te ondersteun.

1. INTRODUCTION

Smart manufacturing (SM) is a transformative approach to industrial production that leverages advanced technologies, data analytics, and intelligent automation to improve the efficiency, productivity, and competitiveness of the product or service [1, 2]. By integrating cutting-edge systems and processes, SMMEs could unlock new levels of operational excellence, adapt rapidly to changing market demands, and stay ahead of the competition in the marketplace [3]. SM is the smooth integration of cyber-physical systems, the Internet of Things (IoT), and data-driven decision-making. This allows SMMEs to achieve greater visibility, control, and optimisation across their entire value chain, starting from the design and production to supply chain and customer services [4]. By embracing SM, SMMEs could streamline their workflows, reduce waste, improve quality, and enhance the overall resilience of their operations. SMMEs are considered the backbone of any national economic development. Their impact on SM is significant, even though their adoption of SM is more difficult than it is for large companies [5].

Recent studies have explained some of the barriers and difficulties faced by SMME owners in adopting SM systems [6, 7]. The scientific body of knowledge discusses various adoption requirements and problems faced by SMMEs. Lin et al. [8] performed an empirical analysis of 80 small manufacturing firms in Taiwan and clustered them on the basis of their degree of IT readiness. Alves [9] analysed data on SMMEs for both the Organization for Economic Co-operation and Development (OECD) and non-OECD companies, and concluded that SMEs were not involved in the deployment of advanced manufacturing technologies (AMTs). Ramdan et al. [10] studied Malaysia's manufacturing SMEs and found that SMEs lacked an innovation culture and strategies to succeed. Various quality management practices in Australian manufacturing SMEs and found that leadership, fact-based decision-making, networking with government bodies and academic institutions, and an ISO 9000 certification were critical success factors for SMEs [10]. The authors [11] concluded that Various quality management practices in the UK and Australian manufacturing SMEs and found that leadership, fact-based decision-making, networking with government bodies and academic institutions, as well as an ISO 9000 certification are critical success factors for SMEs global awareness on manufacturing, frequent employee interaction; attending workshops or conferences outside India, as well as industry-academia interaction are essential activities that foster knowledge creation. Studies have revealed that only a few SMMEs are ready to take the steps to adopt SM practices, despite the numerous benefits that can be derived from its implementation. The lack of willingness to adopt SM may be the result of financial, technological, cultural, operational, or organisational imbalances among business owners [12-14].

The SMMEs that successfully use the emerging evolutionary technology for doing business such as the IoT, big data, artificial intelligence, virtual reality, sensors, and robotics are referred to as SM, smart factory, or Fourth Industrial Revolution (4IR), depending on the writers. Various recent studies have been carried out on the difficulties, benefits, requirements, maturity model, SMME adoption assessment, etc. Adequate studies have not been done on the SM adoption framework specifically to analyse the peculiarities of South African SMMEs [7, 14, 15]. This study therefore seeks to address the SM adoption framework in various SMME sectors in South Africa, with its main focus being on their specific requirements and problems, thereby providing sufficient guidance to solve them. In doing so, the problems are identified and the research gaps are discussed. To end, a possible avenue to address them by creating dedicated maturity models is discussed.

2. THEORETICAL FRAMEWORK

An SMME is defined as a business that has the following attributes: fewer than 250 employees, less than R64 million in annual turnover, less than R10 million in capital assets, and direct managerial engagement by the owners. Small firms need 10 to 50 employees, medium-sized organisations can have up to 250 employees, and micro enterprises can have no more than 10 [16, 17]. In South Africa and worldwide, SMMEs are effective engines of inclusive economic growth and development [18]. The various sectors in South Africa, together with their sizes and turnovers, are shown in Table 1.

Table 1: Classifications of South Africa's SMME sector, size, and annual turnover [19]

S/No	Sector	Size	Maximum turnover (million Rand)
1	Agriculture	Medium Small Micro	35 17 7
2	Accommodation, catering, and others	Medium Small Micro	40 16 5
3	Construction	Medium Small Micro	170 75 10
4	Electricity, gas, water	Medium Small Micro	180 60 10
5	Finance and business services	Medium Small Micro	85 35 7.5
6	Manufacturing	Medium Small Micro	170 50 10
7	Mining and quarrying	Medium Small Micro	210 50 15
8	Motor trade, retail and repair	Medium Small Micro	80 25 7.5
9	Transport, storage, and communication	Medium Small Micro	140 45 7.5
10	Social, community, and personal services	Medium Small Micro	70 22 5
11	Wholesale	Medium Small Micro	220 80 20

If SMMEs in South Africa could leverage SM technology and implement a calculated strategy to break down adoption obstacles, they would have the potential to propel the country's economy to unprecedented heights. Table 2 shows that 903,220 SMMEs are located in Gauteng province. This is the greatest contribution (35.4%) among the provinces, with KZN second (15.3%) and the Northern Cape last at barely 1% (25,577). Table 2 shows the distribution of SMMEs across the South African provinces.

Table 2: Distribution of SMMEs across South Africa's provinces (SEDA 2019)

Province	Number of SMMEs	Distribution Percentage
Gauteng	903,221	35.4
KwaZulu-Natal	390,114	15.3
Limpopo	295,977	11.6
Western Cape	288,195	11.3
Mpumalanga	219,084	8.6
Eastern Cape	179,907	7.1
North West	126,724	5.0
Free State	121,741	4.8
Northern Cape	25,578	1.0
Total	2,550,541	100

This study provides the frameworks and critical actions that SMMEs should take into account to embrace SM practices properly and so maximise their effectiveness. Using cutting-edge technologies, data analytics, and networked systems, SM is a revolutionary approach to industrial production that improves productivity, quality, and efficiency along the whole manufacturing value chain [20]. It signifies a paradigm shift away from conventional production techniques, enabling companies to make data-driven decisions, streamline operations, and quickly adjust to shifting consumer expectations. Fundamentally, SM is the integration of advanced analytics, cloud computing, the IoT, and industrial automation to build an intelligent, flexible, and networked manufacturing ecosystem. Through the real-time data gathering, analysis, and visualisation from several sources that is made possible by this integration, manufacturers could improve their operational efficiency, obtain insightful knowledge, and make more strategic decisions.

3. DEVELOPMENT OF THE STANDARDISED SMMES FRAMEWORK

Previous studies have suggested [21] that an SM adoption framework for SMMEs could be used to determine the needs of a specific SMME in SM. Figure 2 shows the framework requirements and readiness of SMMEs in five steps: (i) determining the manufacturing data that the SMMEs already have; (ii) evaluating the SMMEs' readiness; (iii) persuading the SMMEs' workers to embrace SM; (iv) creating a personalised SM vision; and (v) determining the tools and practices required for implementation [22, 23].

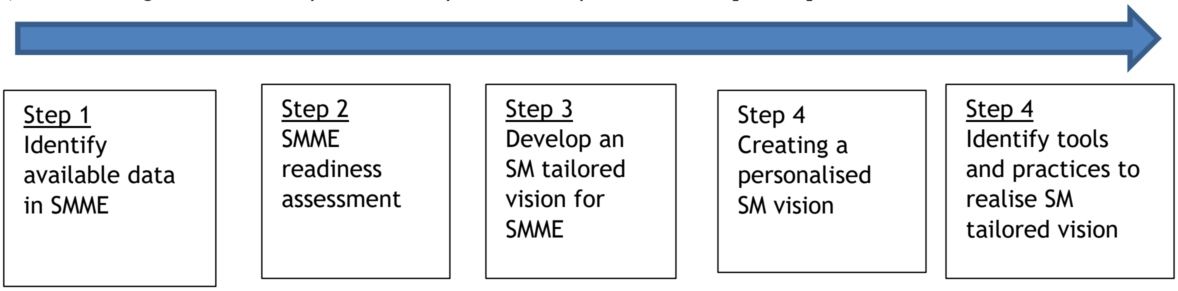

Figure 1: SM adoption framework for SMMEs (adapted from [22])

Step 1: Finding manufacturing data in the SMME that is already available

To enhance manufacturing procedures and goods, SM collects data about a product during every stage of production [24]. The data are used for business decision-making processes, while SM does a thorough examination of the collected data [25]. Moreover, production data can be used both internally and at the company's contact with other supply chain participants [26]. The unique reality, capabilities, and requirements of each SME must be taken into consideration while developing a system for the data that they have supplied. Small businesses primarily keep data on local PCs rather than in systems, although medium-sized businesses show a trend towards centralisation [4]. These data may relate to the organisational dimensions of (a) money, (b) people, (c) strategy, (d) process, and (e) product [27].

Step 2: An evaluation of SMMEs' preparedness

An Irish study claims that the data collection format is typically consistent through time, and is independent of the company's age. Since SMMEs are recognised as having unique resource limitations, including financial, human, and technical ones [28, 29], the preparedness of the company being evaluated should be conducted before taking action [30]. Several maturity models and indices could be used to evaluate an organisation's preparedness for Industry 4.0 [31, 32]. The Singapore smart industry readiness index, which first evaluates 16 aspects in the three areas of process, technology, and organisation, could help to determine the maturity level of SMMEs [33]. That application was expanded to include the five dimensions specified by Pfeifer [22].

Step 3: Engaging SMME management and workers for smart manufacturing

Limitations in human resources have been noted as one of the traits of SMMEs [34]. In addition, these businesses' managerial abilities are significant factors in determining their long-term viability and performance. It is anticipated that future job profiles will have significantly different requirements than those that workers currently need to meet. Managers should be included from the start of the process design, as this has been found to have a positive impact on the long-term growth of SMMEs and to establish a defined role profile for human resources. Therefore, to shift to SM, SMME workers would need to be involved and adopt a new corporate culture, emphasising overcoming human resource restrictions [35].

Step 4: Creating a personalised smart manufacturing vision

The reality of SMMEs has led academics to conclude that SMMEs operate in a reduced and small-scale environment [36]. Because of these businesses' extensive range and expertise, SM strategies ought to be customised around a common core. This step is closely tied to the strategic setup of the companies; it aims to increase the amount of data from acquisition to distribution so that decision-making can be based on data. To facilitate quick decision-making, Industry 4.0 and smart factories as a concept aim to use a large database that is collected, processed, and disseminated [37].

Step 5: Recognising the instruments and methods required for implementation

The selection of suitable instruments for the implementation of an SM and SMME strategy is also customised for SMMEs, based on the specific organisation, much the same as with the preceding processes. Kaartinen *et al.* established the toolkit for SM [38], which has been modified for SMMEs' needs by using a toolkit for transition (Table 3) [39]. The toolkit's toolboxes offer an overview of maturity levels, and typically use five maturity levels to describe an SMME's state of transition towards SM. Level 0, which represents a purely analogue company, is the starting point for companies to implement SM, according to some academics. For these SMMEs, the move from level 0 to level 1 is thought to be the most difficult [40]. The data processing step toolbox is shown in Table 3 [39].

Table 3: SM toolbox corresponding to the data steps (adapted) [39]

	Data hierarchy steps			
SM toolbox	Data generation	Data transmission	Data storage	Data analysis
Business management tools				
Design and simulation toolbox				
Manufacturing toolbox				
Robotics and automation toolbox				
Sensors and connectivity toolbox				
Data analytics toolbox				
Storage/cloud toolbox				

4. METHODOLOGY

The prevailing procedure in scientific research consistently pinpoints and assesses the critical elements influencing the implementation of the desired changes in enterprises. Concerning this goal, we considered an empirical survey to be a helpful method in discovering the decisive variables that would need to be taken into consideration before deciding on the SM adoption framework for enterprises. Improved organisational, operational, and strategic activities could aid in understanding obstacles and identifying the desired variables to strengthen them further. When SM is adapted to take advantage of the innovative methodologies and profit potential, business managers of SMMEs could be provided with crucial information by the analysis's outcomes.

4.1. Assess readiness and identify opportunities

Assessing the current situation of SMMEs and determining the main areas for improvement is the first stage in the adoption framework for SMs [41]. This entails assessing the organisation's culture, personnel competencies, technological prowess, and current production processes to ascertain whether it is ready for the deployment of SM [42]. Identifying the areas that would most benefit from SM solutions and developing a plan for a smooth transition could be done by performing a thorough investigation. Figure 2 shows the functional framework features of future SMME manufacturing systems.

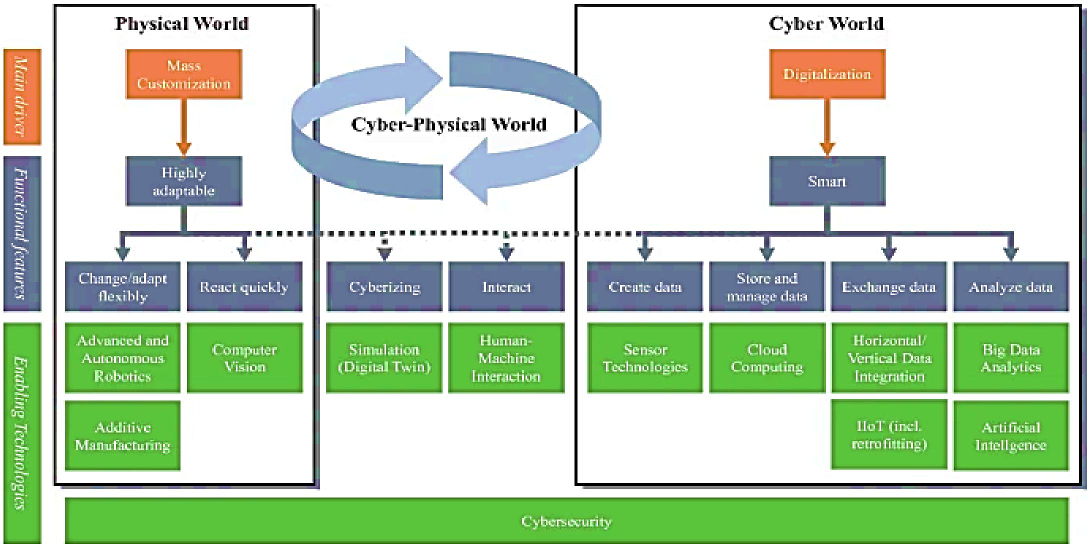

Figure 2: SM framework for SMMEs [43]

4.1.1. Evaluate current capabilities

The first step in assessing an SMME's readiness for SM is to evaluate carefully its current production capabilities, technological infrastructure, and workforce skills [44], conducting a thorough assessment of the existing systems, processes, and data management practices to identify strengths, weaknesses, and areas for improvement. This comprehensive analysis would help to understand the baseline and pinpoint the most pressing needs that SM solutions could address [45].

4.1.2. Analyse industry benchmarks

Comparing the SMME's performance against industry benchmarks and best practices would be crucial for identifying opportunities for SM adoption [41]. Successful case studies of similar SMMEs that have embraced SM should be researched and the key metrics they have improved be understood, such as productivity, efficiency, quality, and customer responsiveness. This benchmarking exercise would help the SMME to set realistic goals and prioritise the areas in which SM could have the most significant impact.

4.1.3. Engage stakeholders

Involving key stakeholders, including employees, suppliers, and customers, in the readiness assessment process would be essential for gaining a comprehensive understanding of an SMME's capabilities and pain points [41]. Feedback and insights from these stakeholders would need to be gathered to uncover hidden problems, unmet needs, and potential roadblocks to SM adoption. By fostering open communication and collaboration, a shared vision could be created and buy-in for the upcoming transformation be built.

4.2. Implementing and optimising smart manufacturing solutions

The application and optimisation of the chosen solutions constitute the last phase of the adoption framework for SM [46]. A deliberate approach would be needed for this phase, which includes choosing and implementing the right technology, educating and retraining staff, and continuously assessing and improving SM procedures. It would be critical to be flexible and agile when putting these solutions into practice. There would be a constant need to get input, assess the data, and make changes to improve the business processes and realise the full potential of SM [47].

4.2.1. Deploy supporting technologies

The deployment of the required enabling technologies would be an essential first step towards the implementation of SM solutions [48]. This would include incorporating automation technologies, advanced data analytics platforms, and IoT sensors into SMME production operations. Through the integration of equipment, real-time data collection, and predictive analytics, it would be possible to establish an intelligent and adaptable production environment that maximised efficiency and adjusted to changing circumstances [49]. This basic infrastructure would make it possible for SMMEs to make a profit from SM.

4.2.2. Upskill and train the workforce

The adoption of SM demands a workforce that is both skilled and flexible. It would be critical to give the staff ample opportunity for training and development when introducing new procedures and technologies [50]. This would entail teaching the workforce about the potential of SM systems, providing them with the tools they would need for data analysis and problem-solving, and cultivating an environment that values ongoing education and creativity. The workforce could unleash their full potential and promote long-lasting gains in output, quality, and efficiency if they were given the tools they needed to adopt and make the most of the new SM solutions.

4.2.3. Continually optimise operations

SM is a continuous process rather than a one-time event. Monitoring, analysing, and optimising production processes regularly would be essential to maximising the returns on new technology investments. The SMME would need to identify bottlenecks, optimise production schedules, and make data-driven decisions by using the real-time data and insights produced by SM equipment [51]. It would also need consistently to evaluate and improve its procedures, taking into account input from staff members, clients, and industry standards. This iterative strategy would support the SMME in remaining innovative, responsive, and at the forefront of SM excellence.

4.2.4. Maturity assessment for smart manufacturing

Evaluating how advanced a manufacturer’s SM capabilities are would be the crucial first step. There are three phases; the beginning, intermediate, and advanced phase. More intermediate manufacturers are using data analytics and increasing automation, while beginner organisations have begun digitalising their processes and linking equipment. Throughout the entire manufacturing value chain, the most advanced businesses have completely integrated and data-driven processes and systems [52].

4.3. Develop a smart manufacturing strategy

Creating a customised SM strategy would be the next step after gaining a thorough insight into the present prospects and capabilities. This would include setting long-term objectives and priorities for important projects, and coordinating the technology spending with the company’s goals. Such a strategy should include a thorough plan for incorporating cutting-edge technology into current operations, such as automated systems, data analytics, and the IoT. Making a plan would help to ensure that the adoption of SM fits in with the SMME’s overall business growth and competitive objectives [53].

4.3.1. Define strategic objectives

Establishing an SMME's strategic objectives would be necessary towards developing an effective SM strategy. This would entail matching SM projects to overarching business objectives, which could include raising customer responses, lowering operating costs, increasing productivity, or improving product quality. It would be important to ensure that SM activities and investments directly assisted the SMME's long-term growth and success by setting clear, quantifiable targets [54].

4.3.2. Assess technological capabilities

One of the most important steps in developing an SM strategy is assessing current technology capabilities. The SMME would need to determine which of the current devices, systems, and data management procedures were compatible with the next SM technologies. To establish a seamless, data-driven manufacturing ecosystem, this assessment would assist the SMME in identifying the gaps that need to be filled, the required improvements, and the new solutions that need to be incorporated [55].

4.3.3. Develop a roadmap

A thorough roadmap for SM transformation would need to be created after the technological evaluation and strategic objectives have been put in place. Putting the projects that would have the biggest immediate impact first and establishing the groundwork for long-term sustainable growth should be prioritised in this roadmap, which should describe the stepwise execution of SM activities. To guarantee that the SMME stays on track and meets its SM objectives, the roadmap should include comprehensive timetables, resource allocation, and significant milestones [56]

4.3.4. Allocate resources

It takes committed financial, human, and technological resources to implement SM solutions [53]. There is a need to carefully plan and budget for the essential expenditures as part of the strategy, such as buying new machinery, updating software and systems, and providing training for staff. The SMME would need to ensure that the SM implementation goes smoothly and successfully, free from unforeseen delays or obstacles, by proactively addressing the resource requirements.

5. ROADMAP DEVELOPMENT FOR SMART MANUFACTURING

5.1. Assess current state

The SMME should begin by thoroughly evaluating its current manufacturing capabilities, processes, and technology, identifying areas of strength and opportunities for improvement that inform the SM roadmap.

5.2. Define future vision

The SMME should establish a clear and ambitious vision for SM transformation. This should align with the organisation's overall business strategy and consider industry trends, customer needs, and competitive factors.

5.3. Prioritise initiatives

The SMME should carefully select the key initiatives that would be required to bridge the gap between the current state and the future vision. It should consider factors such as business impact, technical feasibility, and resource availability when determining the order of implementation.

5.4. Assess technology needs

In adopting SM technologies, It is crucial to assess carefully the specific needs and pain points of the organisation [57]. A thorough analysis of the current processes should identify areas for improvement and determine which smart technologies could address those needs most effectively [58].

5.5. Evaluate technology options

The SMME should find and evaluate the range of SM tools, such as industrial automation, sensors, data analytics, and cloud computing [59]. It should compare their features, capabilities, and compatibility with the existing systems to identify the most suitable solutions for the business.

6. DIFFICULTIES FACED BY SMMES IN ADOPTING SMART MANUFACTURING

While the benefits of SM are substantial, SMMEs often face unique difficulties in embracing this transformative approach [60]. Limited financial resources, A lack of technical expertise, and resistance to change can create significant barriers to the adoption of SM. In addition, many SMMEs struggle to navigate the complexities of integrating advanced technologies into their existing operations, further compounding the difficulties they face. The following are the basic problems that SMMEs face in SM practices.

6.1. Financial

Insufficient capital investments: SMME owners typically have tighter budgets than larger enterprises [61], making the upfront costs associated with SM technologies a significant hurdle. Securing funding for equipment, software, and infrastructure upgrades can be a daunting task, hindering their ability to invest in these transformative solutions.

6.2. Operational

Skills and knowledge gaps are some of the challenges that confront SMME business owners. Implementing SM often requires specialised technical skills and a deep understanding of data analytics, automation, and digital integration [62]. Many SMMEs lack in-house expertise, leading to difficulties in identifying, deploying, and maintaining these advanced systems, ultimately slowing down their adoption of SM.

6.3. Organisational resistance to change

Transitioning to SM can disrupt established workflows and challenge traditional mindsets. SMMEs may face resistance from employees who are hesitant to embrace new technologies and processes, making the change management aspect of SM adoption a significant challenge to overcome.

Addressing these issues requires a comprehensive and strategic approach that is tailored to the unique needs and constraints of SMMEs. Overcoming these barriers would be crucial if SMMEs were to reap the full benefits of SM and maintain their competitiveness in the rapidly evolving industrial landscape [63].

7. THE FUTURE OF SMMES, AND RECOMMENDATIONS

The adoption of SM demands a comprehensive change management approach. This includes engaging staff, promoting a culture of innovation, and encouraging continual development. Employees must be empowered and prepared to adapt to changing technologies and ways of working. Regular training, feedback loops, and recognition programmes could help to foster the cultural transition.

Organisations should also build a continuous improvement process that includes reviewing progress, identifying bottlenecks, and iterating on the SM roadmap. This agile strategy, when combined with change management, would allow businesses continually to optimise their SM capabilities and stay ahead of the curve [64].

8 CONCLUSION

For any SMME that embarks on the journey of SM adoption, it would be crucial to embrace the transformative potential of this technological revolution. By implementing the comprehensive framework outlined in this presentation, an SMME could discover new levels of efficiency, flexibility, and competitiveness, positioning it for long-term success in the rapidly evolving industrial landscape [65]. It would need to engage actively with industry associations, technology providers, and other SMMEs to build a collaborative SM ecosystem [66]. By sharing best practices, exchanging knowledge, and exploring joint initiatives, the SMME could accelerate its SM maturity, leverage collective expertise, and access a wider pool of resources and support. Leveraging these strategic partnerships can help it to stay at the forefront of industry trends and unlock new avenues for growth and innovation. Transitioning to SM is an ongoing process, not a one-time event. SMMEs need to adopt a flexible, agile mindset that embraces continuous learning and adaptation. As technologies, market demands, and customer preferences evolved, business owners would need to reassess strategies, reallocate resources, and pivot approaches accordingly. By maintaining a long-term, forward-thinking perspective, managers could ensure that their SMME remains resilient, responsive, and at the cutting edge of SM excellence.

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