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DETERMINANTS OF AGILE MANUFACTURING SYSTEMS ADOPTION AND ITS IMPACT ON OPERATIONAL PERFORMANCE AMONG SMALL AND MEDIUM-SCALE ENTERPRISES (SMEs) IN OGUN STATE, NIGERIA

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Abstract: *Manufacturing firms today face demand volatility, shorter product lifecycles, and increasing global competition, making traditional production systems inefficient. Agile Manufacturing Systems offer a suitable response, allowing organisations to adjust their production capacity fast in light of changes in the market and maintaining their performance across all aspects. The study uses a positivist cross-sectional survey method based on the Technology-Organization-Environment (TOE) Framework, Dynamic Capabilities Theory, and the Resource-Based View. A closed-ended questionnaire on a Likert scale (α range: 0.803–0.889) was conducted among 365 manufacturing small and medium-scale enterprises (SMEs) in Ogun State, Nigeria, with 239 valid responses collected (response rate = 65.5%). Multiple ordinary least squares regression [$F(3, 235) = 80.993$, $p < 0.001$], five simple linear models, and one-way ANOVA tests for moderating firm size were used. A three-factor TOE model accounted for 50.8% of the variance in adoption ($R = 0.713$, $R^2 = 0.508$). Organisational ($\beta = 0.415$, $t = 9.062$, $p < 0.001$) and environmental factors ($\beta = 0.413$) exerted comparably strong effects, both substantially exceeding the effect of technological factors ($\beta = 0.345$). The use of Agile Manufacturing Systems positively influenced all five performance criteria measured: Delivery Reliability ($R^2 = 0.474$), Product Quality ($R^2 = 0.466$), Manufacturing Lead Time ($R^2 = 0.463$), Production Flexibility ($R^2 = 0.450$), and Cost Efficiency ($R^2 = 0.426$). Firm size had no moderating effect on adoption [$F = 0.190$, $p = 0.663$, $\eta^2 = 0.001$]. The study shows the adoption of AMS is basically an organisational strategic process and has little relation to firm size. An excess emphasis on organisational factors raises concerns about the technology-driven perspective of the concept and implies far-reaching consequences for SME policy and strategy.*

Key words: Agile Manufacturing Systems; Operational Performance; SMEs; TOE; Industry 4.0; Manufacturing Flexibility

1 Introduction

Manufacturing has traditionally served as the primary agent of economic transition in both developed and developing countries, adding value to their abundant raw materials and generating job opportunities, innovations, and technology acquisition (Paul and Ofuebe, 2021; Omoniyi et al., 2026). The sector's potential to facilitate structural changes in an economy is well established in the development literature. By moving production away from subsistence agricultural activities toward more efficient industrial processes, manufacturing offers considerable value to nations at all stages of development. Yet despite being the largest economy and population centre in Africa, Nigeria has suffered from substandard performance of its manufacturing sector, producing only 8.4% of its GDP in 2022 (Madueme et al., 2022; Jacob and Umoh, 2025) and thereby failing to capitalise on its considerable productive capability.

According to (Sunday and Ariyo, 2017; Olanrewaju et al., 2026) SMEs, which can be described as businesses employing less than 200 individuals, form the basis of manufacturing activities in most developing economies. This is more evident in industrialized areas like the Ogun State region, one of Nigeria's top manufacturing regions due to the high number of registered firms (Maradesa and Ojo, 2024). In Ogun State (Figure 1), SMEs account for employment of more than 400,000 people and add value to food processing, textile production, chemicals and fabrication industries, among others (Maradesa and Ojo, 2024; Abiola and Oluwole, 2025). However, the operation of the enterprises is complicated by the accumulation of challenges, including inadequate infrastructure, energy shortages, technological dependency, and rising market volatility (Okoye and Mensah, 2025)

Figure 1: Map of Nigeria showing Ogun State

Manufacturing systems of today are distinctively different from those in the past, which were characterized by predictability, economies of scale, and standardization (Wang et al., 2021; Maradesa and Ojo, 2024; Omoniyi et al., 2026). The product lifecycles have been drastically compressed in many industries, from years to months. Customer demands have diversified, resulting in the need for customized solutions offered at scale production prices. Technologies related to the fourth industrial revolution have impacted supply chain practices and created competitive standards (Nimawat and Gidwani, 2022). Against this backdrop, companies whose business model is premised on inflexible, optimized-for-volume production systems are faced with competitive handicaps.

Agile Manufacturing Systems (AMS) (Figure 2) represent a promising strategy and engineering approach to this situation. First conceived by (Yusuf et al., 1999) and then codified by (Gunasekaran, 1999). AMS represents a model in which production systems can be quickly and cost-efficiently configured in response to changes in consumer behavior, technological advancements, and competitive dynamics. This is accomplished by combining flexible manufacturing machinery, modular product design, real-time information systems, multi-skilled employees, and collaboration along the supply chain. This allows for the improvement of lead time, reliability, quality, and cost-effectiveness simultaneously (Gunasekaran et al., 2019).

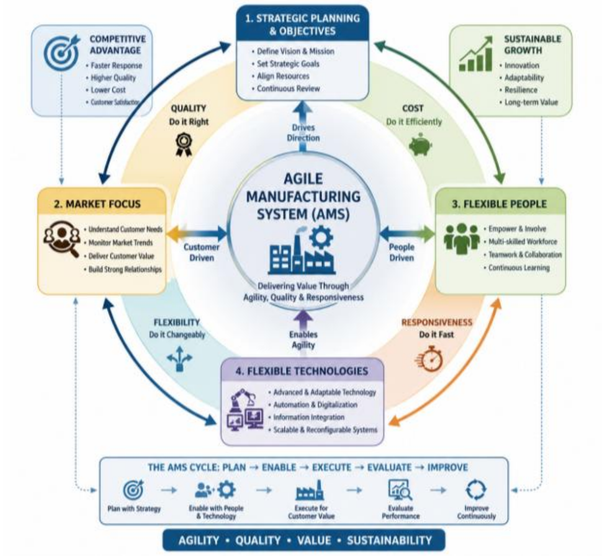

Figure 2: Agile Manufacturing System (AMS)

The predominant manufacturing structures used by SMEs in Ogun State are rigid and batch-based production processes (Egwakhe et al., 2021). This includes production processes with long setup times, manual process controls, low level of automation, and poor digital planning tools. The rigidity of such production structure results in operational problems such as longer manufacturing lead time, poor delivery performance, inability to customize products, and higher per-unit cost (Gunasekaran, 1999; Ogunleye et al., 2021). Though an agile manufacturing system (AMS) provides a well-founded solution to this problem, there is insufficient empirical evidence concerning AMS adoption in the context of Nigeria and other parts of Sub-Saharan Africa. Most global literature focuses on AMS adoption among large manufacturers in developed countries or industrial giants such as India and China, which do not share the same circumstances as SMEs in Ogun State (Ali and Wasim, 2022; Kumar et al., 2022).

The purpose of this study is to provide a comprehensive analysis of the factors influencing AMS adoption and its potential contributions to improving operational performance of manufacturing SMEs in Ogun State. To achieve this aim, four distinct research objectives are proposed. First, estimate the impact of technology, organization, and environment on AMS adoption. Second, assess the effect of AMS adoption on five different performance dimensions. Third, test whether firm size mediates the impact of AMS adoption. Fourth, identify key drivers and obstacles of AMS adoption in Ogun State. Based on these objectives, the study tests four null hypotheses. Specifically, there is no significant impact of technology, organization, or environment factors on AMS adoption and there is no significant positive impact of AMS adoption on any performance dimension.

2. Literature Review

There are a series of paradigm shifts in the intellectual history of manufacturing, influenced by both technological advances and current market needs. Craft manufacturing before the 1920s emphasized craftsmanship but was lacking scalability (Hayes and Pisano, 1996). Mass production started around the 1920s to 1970s and is associated with the implementation of the Fordist assembly line approach. It was able to attain great economies of scale through the use of standardization; however, its rigidity and fragility made it unsustainable in the face of diversifying market conditions (Hayes and Pisano, 1996; Honda, 2002). On the other hand, Lean Manufacturing started around the 1980s to 2000s and was based on the principles of the Toyota Production System. It was all about the concepts of quality and waste reduction as key elements, showing that reliability and efficiency are not mutually exclusive approaches (Leksic et al., 2020). Nevertheless, the applicability of lean systems in volatile and unpredictable market conditions with diverse products proves problematic (Khalfallah and Lakhal, 2021). The arrival of the era of Industry 4.0, which entails cyber-physical systems, the Internet of Things, big data analysis, cloud computing, additive manufacturing, and artificial intelligence, sets the grounds for yet another paradigm shift, where mass customization and real-time adaptive optimization can become possible (Xu et al., 2018; Aheleroff et al., 2021).

Table 2.1. Comparative Evolution of Manufacturing Paradigms

Dimension	Mass Production	Lean Manufacturing	Flexible Manufacturing Systems	Agile Manufacturing
Primary Goal	Scale & cost	Waste elimination	Volume/variety flex.	Rapid responsiveness
Environment	Stable, predictable	Stable, low variety	Variable volume	Volatile, unpredictable
Product Strategy	Standard, high vol.	Standard, JIT	Moderate variety	Mass customisation
Decision Making	Centralised	Process-disciplined	Programmed	Decentralised, empowered
Technology	Mechanisation	JIT, Kanban, TPM	CNC, FMS, CIM	IoT, AI, ERP, CAD/CAM, AM
Labour Model	Deskilled, specialist	Multi-skilled, teams	Technically skilled	Knowledge workers
SME Applicability	Low	Medium	Low–Medium	High

(Sources: Gunasekaran et al., 2019; Khalfallah and Lakhal, 2021; Ding et al., 2023)

2.1 Types and Classifications of Agile Manufacturing Systems

The conceptual foundations of agile manufacturing are broadly shared, the literature distinguishes several forms AMS can take depending on a firm's production context and strategic focus. A primary distinction is drawn between product agility and process agility (Sharifi and Zhang, 1999; Gunasekaran et al., 2019). Product agility refers to a firm's capacity to introduce new or customised product variants rapidly, typically achieved through modular design and platform-based engineering, and is most prevalent among discrete manufacturers such as fabrication, electronics, and assembly-based firms. Process agility, by contrast, concerns the speed and flexibility with which production processes themselves can be reconfigured, scaled, or redirected, a form more commonly associated with process industries such as food and chemical manufacturing, where product variety is constrained by the underlying production technology but throughput and formulation flexibility remain critical competitive levers.

A second classification distinguishes strategic agility from operational agility (Sherehiy and Karwowski, 2014). Strategic agility operates at the level of organisational decision-making, encompassing a firm's capacity to sense market shifts and reorient its competitive positioning, product portfolio, or business model accordingly. Operational agility, in contrast, operates at the shop-floor level, concerning the physical and procedural capacity to reconfigure machinery, schedules, and workflows in response to demand fluctuations. Most empirical AMS instruments, including elements of the framework applied in the present study, measure operational agility more directly than strategic agility, since the latter is harder to operationalise through structured survey items.

A third useful distinction, particularly relevant to SME contexts such as Ogun State, separates resource-intensive AMS, dependent on substantial investment in flexible automation, robotics, and advanced ICT integration, from capability-based AMS, which achieves agility primarily through organisational practices such as cross-functional teaming, multi-skilled labour, and decentralised decision-making, with comparatively modest technological investment (Sindhwani et al., 2020; Manesh and Schaefer, 2020). This distinction is directly relevant to the present study's findings, since it offers a conceptual explanation for why organisational and environmental factors, rather than technological factors, emerge as the dominant predictors of adoption among resource-constrained Nigerian SMEs, suggesting these firms are more likely to pursue capability-based rather than resource-intensive forms of agility.

2.2 Conceptual Architecture of Agile Manufacturing Systems

(Yusuf et al., 1999) Defined agility as the ability of a manufacturing firm to thrive in a competitive environment full of uncertainties and changes by quickly responding to markets created from customer-designed products and services. This definition includes several characteristics of an agile firm such as responsiveness, competency, flexibility, and quickness. In broad terms, an agile manufacturing organization is supported by four major foundations that determine the level of its capabilities. First, such an entity possesses modular product architecture characterized by assembling products using standardized and interchangeable modules with clear interfaces (Gunasekaran et al., 2019). It implies that an organization can easily change product varieties and implement mass customization without changing its architectural framework. Second, there is information technology integration, which involves leveraging Enterprise Resource Planning (ERP), Manufacturing Execution System (MES), Computer-Aided Design / Computer-Aided Manufacturing (CAD/CAM), and Product Lifecycle Management (PLM) systems for creating a single digital thread connecting product design and development, purchasing, manufacturing, and delivery (Nimawat and Gidwani, 2022). ERP software allows combining the flow of enterprise-wide information to track inventory and capacity; MES software is used to monitor shop-floor operations; CAD/CAM systems are instrumental in reducing the time spent introducing a new product to the market; and PLM systems help maintain consistency in product designs throughout the entire lifecycle. These capabilities become even more advanced through the implementation of the third pillar involving sensors powered by IoT that allow continuous machine and process monitoring, along with applying AI techniques for predictive maintenance, forecasting of quality and demand (Koren et al., 2015; Nimawat and Gidwani, 2022).

The third pillar itself is also expanded by the establishment of corporate partnerships or virtual enterprises whereby external entities, including suppliers, customers, and logistics companies, may be dynamically created and disbanded depending on specific circumstances to leverage the available competencies, distribute risks, and increase resources. These three foundations are rooted in the fourth one, namely the culture of a knowledge-based organization focused on Six Sigma philosophy that encourages reducing defects via statistical methods and Kaizen that relies on constant and continuous improvements performed by employees (Sharma et al., 2022).

2.3 Theoretical Framework

According to the TOE framework by (Tornatzky and Mitchell, 1990), technology adoption depends on three contextual factors. Firstly, technological context consists of internal and external technologies pertinent to the firm already implemented or available for use. Secondly, organizational context includes firm size, the level of centralization, the management system and quality of human resources; and thirdly, environmental context involves industry structure, competitive nature, and regulation. The TOE framework has been empirically tested in the ERP, cloud computing and Industry 4.0 adoption arenas (Satyro et al., 2024; Zhou et al., 2024). TOE is useful because its multi-level view helps to counteract technological determinism in models such as TAM.

The concept of dynamic capabilities theory was described by (Teece et al., 1997) whereby the dynamic capabilities of firms can be described as the ability of firms to reconfigure, create, and integrate external and internal capabilities to cope with changes in their environment. In relation to this theory, the adoption of AMS is based on the integration of the following three microfoundations of dynamic capabilities theory: sensing, which entails the identification of changes in markets as well as technological opportunities; seizing, whereby firms allocate their resources to utilize identified opportunities by adopting AMS; and reconfiguration, which implies the continuous adaptation of a firm's resources to meet competitive conditions. Overall, it can be deduced that organizations with high levels of dynamic capabilities are likely to adopt AMS and perform well.

The Resource-Based View introduced by (Barney, 1991) states that sustainable competitive advantage arises from resources owned by firms that are Valuable, Rare, Inimitable, and Non-substitutable (VRIN). If agile manufacturing capabilities are ingrained in organizational routines and culture rather than being physically implemented, they constitute VRIN resource combinations that cannot easily be copied by other firms. Thus, this theory is instrumental in understanding the greater influence of organizational factors on AMS advantage over technological factors: since capabilities are tacit, path-dependent and socially-based, they are inherently difficult to copy.

2.4 Determinants of AMS Adoption

Before narrowing to the specific predictors examined in this study, it is useful to situate them within the broader AMS adoption literature, which generally converges on three overarching determinant categories, broadly mirroring the technological, organisational, and environmental contexts of the TOE framework (Tornatzky and Mitchell, 1990). Technology-related determinants span the availability, cost, and compatibility of flexible production equipment and digital infrastructure; organisational determinants encompass managerial commitment, workforce competence, and strategic orientation; and environmental determinants capture external competitive and regulatory pressures. The following subsections examine each category in greater depth within the present study's Nigerian SME context.

According to (Agarwal et al., 2023) and (Lokhande and Sarode, 2023), technological readiness, referred to as the extent of the presence or availability of the technologies required for AMS deployment by an organization, is considered a key predictor of adoption. The concept includes flexible production technologies like CNCs and robotic technologies (Mehrabi et al., 2000; Groover, 2010); incorporation of ICT such as ERP, MES, SCADA, and IoT-based solutions (Nimawat and Gidwani, 2022; Soori et al., 2024); as well as the alignment of agile technologies with legacy systems (Ghobakhloo et al., 2022). However, these are all compounded in developing nations due to issues related to financial constraints, lack of technical expertise, and high costs involved in acquiring technologies (Fanelli, 2021).

Aside from the technological variables, the organisational factors of adopting firms have consistently been shown to be the most powerful determinants of the successful AMS adoption process in manufacturing SMEs (Ghobakhloo et al., 2022; Kanishka and Acherjee, 2023). Major organisational determinants in the adoption process include the commitment level of top management to shape resource mobilisation and the culture orientation to agile production; workforce technical competencies and multi-skilling; organisational culture innovation-friendly and fast-decision-making; strategic orientation towards agility; and financial slack, whereby there are sufficient resources for investment in an agile production setup. In support of this observation, the Dynamic Capabilities theory predicts that the organisational factors will take precedence over technological determinants in the prediction of successful adoption due to the path-dependent and inimitable nature of organisational capabilities (Teece et al., 1997; Mohaghegh et al., 2024).

As a complement to the above internal driving factors, external driving forces, or environmental factors, create extra pressure and drive on the part of the organisation to embrace AMS. The main environmental determinants include intense competition from local and foreign competitors; differences in customer demands and the necessity of customising the products; regulations; safety concerns; and technology trajectory in the environment. In particular, the Ogun State environment poses increasing pressures on the manufacturing organisations because of the rise in competition from imports and the rising need for customised products, thus making agility adoption not just a voluntary but rather a necessary strategy (Ogunmuyiwa and Adetayo, 2023). Indeed, the TOE framework supports this view in arguing that it is the firms facing high environmental pressure who are motivated to pursue an AMS strategy (Satyro et al., 2024).

2.5 AMS and Operational Performance: Empirical Review

There exists consistent empirical evidence in support of the positive correlation between AMS adoption and operational performance in manufacturing organizations. The study by (Kumar et al., 2022) using the PLS-SEM model shows that the application of agile manufacturing practices enhances delivery performance, production flexibility, and consistency in quality. Similarly, it was demonstrated by (Mohaghegh et al., 2024) that the adoption of AMS mediates the relationship between dynamic capabilities and sustainable business performance. (Alamri et al., 2024) also demonstrated the superiority of agile managerial methods compared to both traditional and flexible management methods in terms of performance outcomes in a volatile market environment. As regards the literature on the topic specific to SMEs, the adoption of AMS improves performance in small manufacturing enterprises, according to the study by (Ali and Wasim, 2022). In addition, (Khalfallah and Lakhal, 2021) demonstrated that a combination of lean foundations and agile capabilities brings synergetic performance benefits. While the literatures establishes a robust general case for AMS adoption, it largely overlooks the structural realities that distinguish SMEs in developing economies from the firms examined in this review.

Challenges specific to SMEs adopting AMS in developing countries include additional factors not accounted for by the three primary constructs of the TOE model (Díaz-Arancibia et al., 2024). Insufficient financing opportunities owing to poor collateral and credit systems limit investments in an agile technology environment. It is a factor that is not fully addressed by TOE's construct on technological environment, where the lack of affordability is seen as a less significant challenge than other issues (Fanelli, 2021; Ghobakhloo et al., 2022).This is also due to poorly developed technical training and education institutions, which contribute to skill shortages and limit the usefulness of TOE's approach to treating labour competence as a purely internal construct of the organisation (Tornatzky and Mitchell, 1990; Lokhande and Sarode, 2023). In addition, inadequate energy supply and connectivity infrastructure result in increased costs for alternative power solutions, which are not reflected in TOE's environmental construct (Tornatzky and Mitchell, 1990; Nimawat and Gidwani, 2022; Ogunmuyiwa and Adetayo, 2023). Further, a more informal network of suppliers limits the possibility of forming partnerships expected by agility theory (Sharma et al., 2022; Bego and Mattos, 2024).

Although there have been considerable advancements in the AMS body of knowledge, some limitations still exist. Most of the literature available focuses on big firms and developed nations, suggesting whether the conclusions arrived at can be readily transferred to small firms operating in underdeveloped countries. The review shows a dearth of literature to quantify all three dimensions of the TOE framework to determine the combined effect of these dimensions on the firm’s operational performance from five different angles within a Nigerian SMEs’ setting. This has a significant effect on the accuracy of policy recommendations based on this knowledge gap. Finally, empirical research on how the firm’s size affects AMS adoption among Sub-Saharan African manufacturing SMEs has not yet been conducted.

2.5 Recent Evidence from Sub-Saharan African SME Manufacturing

Some recent studies have focused on technology adoption barriers faced by manufacturing small and medium enterprises in Sub-Saharan Africa. (Peter et al., 2023; Onu et al., 2024) explored the adoption of the concept of Industry 4.0 among SMEs in Sub-Saharan Africa, offering an excellent basis for exploring the concept of AMS within a larger trend digitalisation. Aryeetey and Baffour (2022) conducted research on manufacturing competitiveness determinants by analyzing panel data for 41 African nations between 2003 and 2018. They found evidences such as lack of adequate infrastructure like ports, roads, and electric power. Combined with bureaucracy and high levels of corruption. According to them, these problems increase the costs of operations and have adverse effect on SMEs industries. They suffer the most since they face the greatest challenges associated with these problems. In a similar manner, Adegboye and Iweriebor (2018) employed the World Bank's Enterprise Survey database to test the hypothesis concerning the benefits of financial resources in fostering innovation and boosting the performance of SMEs businesses in Nigeria.

In addition, Onu et al. (2024) broadened this geographical picture by analyzing the uptake of Industry 4.0 ideas in manufacturing SMEs in Sub-

Saharan Africa, placing the AMS concept in the broader context of inadequate digitalization. Achieng and Malatji (2022), through their scoping literature review, proved that the problems facing African SMEs in digital transformation is a developing field of study. All of the above-mentioned literature demonstrates a continuous lack of systematic AMS approaches in SMEs due to inadequate adoption initiatives, which aligns with the current paper's findings.

3. Research Methodology

The study adopted a positivist epistemology since it is based on the assumption that social phenomena may be objectively measured, and their causes established through empirical observations (Saunders et al., 2007). In a deductive mode of inquiry, the theoretical propositions postulated based on the frameworks of the theory of enterprise architecture, dynamic capabilities theory, and resource-based view are operationalised into specific hypotheses to undergo testing using empirical data. The use of a quantitative cross-sectional survey allows for empirical estimation of population parameters based on the systematic measurement of variables in a representative sample within one time period, thereby addressing the purpose of the study.

The study's target population comprised all manufacturing SMEs registered within Ogun State, Nigeria. The minimum sample size was calculated using the Krejcie and Morgan (1970) formula:

$$n = \frac{x^2 NP(1-P)}{d^2(N-1) + x^2 P(1-P)} \qquad (1)$$

where: n = required sample size; χ^2 = chi-square critical value at 95% confidence (df=1) = 3.841; N = 820; P = 0.50 (maximising variance); d = 0.05. Substituting:

$$n = \frac{3.8416 \times 820 \times 0.25}{0.0025 \times 819 \times 3.8416 \times 0.25} = \frac{787.528}{3.0079} = 261.8$$

Non-response adjustments of 10% were made on the Krejcie and Morgan (1970) minimum figure, giving a tentative sample size of 289. Nevertheless, operational difficulties arising out of the data collection process especially in collecting the questionnaires at SME locations scattered in different places within the specified time frame made it imperative to distribute more questionnaires (365 in all) among the five subsectors. This increase was in addition to the calculated sample size because the expected shortfall in valid responses required an increase beyond the calculated figure. The result of the survey was a total of 239 valid respondents with a response rate of 65.5%, which is more than adequate to ensure stability in regression estimates because of at least 10 observations per predictor (Hair et al., 2019). A multi-stage stratified random sampling strategy was used in selecting the sample with firms being stratified according to sub-sector and company size. Subsequently, a random sampling technique was used within each of the defined strata based on the relative size of each stratum's population.

The population register (N= 820) consisted of names drawn from registers supplied by the Ogun State Ministry of Commerce and Industries, as well as MAN Ogun State Chapter, and thus constitutes the most recent available data on the population of Ogun State manufacturers available to the research team between April 10 and December 22, 2025. It is evident that the population of Ogun State manufacturers is not homogeneously distributed among these subsectors and is actually heterogeneous, in line with Krejcie & Morgan (1970), who recommended using stratified random sampling in cases when the population consists of different classes. The proportionate random allocation method was used in this study since this would give the most representative result, in accordance with the distribution of manufacturing subsectors in Ogun State. It should be noted that we did not keep records about the distribution of respondents at the sector level separately, but rather counted only the number of responses at the sector level.

The data collection tool consisted of a structured questionnaire with six main parts. Construct items were measured on a five-point Likert Scale (Strongly Disagree = 1 to Strongly Agree = 5) in line with common practice in manufacturing adoption and performance studies. A total of five constructs were conceptualised, namely, Technological Factors (TF, 5 items); Organisational Factors (OF, 5 items); Environmental Factors (EF, 5 items); AMS Adoption (AMA, 5 items); and Operational Performance (OP, 25 items). Items measuring five different sub-dimensions of OP were included. Content validity was assessed via structured expert reviews conducted by three academicians and two industry experts in manufacturing engineering SMEs. To examine construct validity, exploratory factor analysis was conducted, demonstrating validity since all items loaded above 0.60 on the appropriate constructs.

Cronbach's alpha (α) was used to test internal consistency reliability, with α > = 0.70 deemed satisfactory (Tavakol and Dennick, 2011). Table 3.1 presents Cronbach's alpha values for all constructs

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Table 3.1. Reliability Statistics of Study Constructs.

Construct	Items	Cronbach's α	Reliability Level
Technological Factors (TF)	5	0.821	Good
Organisational Factors (OF)	5	0.847	Good
Environmental Factors (EF)	5	0.803	Good
AMS Adoption (AMA)	5	0.836	Good
Operational Performance (OP — all 5 dims)	25	0.889	Excellent

Source: (Tavakol & Dennick, 2011).

Table 3.2: Exploratory Factor Analysis

Construct	Item	Factor Loading	KMO	Bartlett's χ^2 (df=10)
Technological Factors (TF)	TF2	**0.834**	**0.880**	$\chi^2 = 663.980$, $p < .001$
	TF4	**0.799**		
	TF3	**0.792**		
	TF5	**0.786**		
	TF1	**0.772**		
Organisational Factors (OF)	OF1	**0.844**	—	$\chi^2 = 703.573$, $p < .001$
	OF5	**0.815**		
	OF4	**0.807**		
	OF3	**0.793**		
	OF2	**0.787**		
Environmental Factors (EF)	EF2	**0.884**	—	$\chi^2 = 974.265$, $p < .001$
	EF3	**0.872**		
	EF1	**0.863**		
	EF4	**0.856**		
	EF5	**0.841**		
AMS Adoption (AMA)	AMA2	**0.792**	—	$\chi^2 = 508.015$, $p < .001$
	AMA5	**0.775**		
	AMA4	**0.738**		
	AMA3	**0.725**		
	AMA1	**0.704**		
Operational Performance (OP)	OP2	**0.808**	—	$\chi^2 =$ —, $p < .001$
	OP5	**0.797**		
	OP1	**0.792**		
	OP3	**0.746**		
	OP4	**0.722**		

Table 3.2 shows all items of the five constructs were retained after performing exploratory factor analysis, with factor loadings ranging between 0.704 and 0.884 (Table 3.2), far exceeding the minimum of 0.60 (Watkins, 2018). The sample size for all constructs was adequate (KMO ≥ 0.80) and the Barlett's Test of Sphericity was highly significant (p<.001) for all constructs.

3.1 Analytical Model Specification

A Multiple OLS regression model was specified to test the Hypotheses

$$AMA_i = \beta_0 + \beta_1 TF_i + \beta_2 OF_i + \beta_3 EF_i + \varepsilon_i \qquad (2)$$

where AMA_i = composite AMS adoption score for firm i; β_0 = regression intercept; β_1, β_2, β_3 = partial regression coefficients; ε_i = error term with $E(\varepsilon_i) = 0$ and $Var(\varepsilon_i) = \sigma^2$ (homoscedasticity). Standardised beta coefficients (β^*) enable direct inter-predictor comparison. Multicollinearity was assessed using Variance Inflation Factors (VIF); all VIF values were confirmed < 5.

Five separate simple linear regression models were tested

$$OP_{ik} = \alpha_{0k} + \alpha_{1k} AMA_i + \varepsilon_{ik} \qquad (3)$$

$$k = 1, 2, 3, 4, 5$$

where OP_{ik} = score on the k-th performance dimension (k: 1=Production Flexibility, 2=Manufacturing Lead Time, 3=Delivery Reliability, 4=Cost Efficiency, 5=Product Quality); α_{1k} = regression coefficient for AMS adoption effect. All models were evaluated at $\alpha = 0.05$.

One-way ANOVA tested whether mean AMS adoption scores differ across firm size categories. Levene's Test for Equality of Variances ($F = 0.670$, $p = 0.414$) confirmed homogeneity. Effect size was quantified using partial eta-squared (η^2); $\eta^2 < 0.01$ indicates negligible practical significance (Cohen, 1988).

$$H_0 : \mu_{small} = \mu_{medium} \text{ vs } H_1 : \mu_{small} \neq \mu_{medium} \qquad (4)$$

4. Results and Discussion

Totally, 365 questionnaires were sent out; of these, 239 were fully completed, translating to a response rate of 65.5%. This rate goes past the standard 60% cut-off that is considered satisfactory for quantitative survey research (Bell et al., 2022). The breakdown by gender is evenly split between males and females (51.9%; 48.1%, respectively). The most common age group was 35-44 years (23.4%), implying that there was enough experience within the sample size. Regarding position, the two most common types were supervisors (23.4%) and "other" (including owners) (23.4%). Next came engineers/technicians and managers (18.4% each), followed by operators (16.3%). In relation to the firm age group, the biggest proportion was from SMEs running for over 15 years (28.5%), meaning that this research setting was quite mature. Regarding firm size, small organizations were predominant (less than 50 employees: 59.8%; medium-size: 50-199 employees: 40

4.1 Multiple Regression: Determinants of AMS

Model summary is provided in Table 4.2 for the multiple regression analysis. The model is a well-fitting one since the value of R is 0.713, implying a large positive association in a multivariate sense. According to the coefficient of determination (R^2), 50.8% of the variance in AMS adoption can be attributed to the TOE-framework factors; therefore, the effect size is large (Cohen's $f^2 = R^2/(1 - R^2) = 1.033$ compared to the standard large $f^2 = 0.35$). The null hypothesis of no linear association is rejected at the omnibus significance level because the value of the F statistic is 80.993 with a probability less than 0.001.

The estimated regression equation is:

$$AMA_i = 0.645 + 0.314 TF_i + 0.352 OF_i + 0.299 EF_i \qquad (5)$$

4.2 AMS Adoption and Operational Performance

Five simple linear regression equations were constructed. The summarized findings are presented in Table 4.4 and indicate strong evidence in favor of H_4 for all five constructs. AMS adoption explains a variance of 42.6% to 47.4%, depending on the dimension, which demonstrates large effect sizes, especially considering that all models have only one explanatory variable.

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Table 4.2. Multiple Regression Model Summary

Model	R	R^2	Adj. R^2	Std. Error	F-Change	df_1	df_2	Sig. F
1	**0.713**	**0.508**	0.502	1.799	**80.993**	3	235	**<0.001*** **

Note: Predictors: Technological, Organisational, and Environmental Factors. Cohen's f^2 = 1.033 (large effect). Statistical Power > 0.99. *** $p < 0.001$.

Table 4.1. Demographic and Firm Profile of Respondents

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	124	51.9
	Female	115	48.1
Age (Years)	Below 25	34	14.2
	25–34	49	20.5
	35–44 (modal)	56	23.4
	45–54	50	20.9
	55 and above	50	20.9
Position	Engineer/Technician	44	18.4
	Manager	44	18.4
	Operator	39	16.3
	Supervisor (modal)	56	23.4
	Other (incl. owners)	56	23.4
Years in Operation	Below 5 years	59	24.7
	5–9 years	53	22.2
	10–14 years	59	24.7
	Above 15 years (modal)	68	28.5
Firm Size	Small (<50 employees)	143	59.8
	Medium (50–199 employees)	96	40.2
Sector	Food Processing	43	18.0
	Textile & Garments	41	17.2
	Fabrication & Metal	46	19.2
	Chemical & Pharmaceutical	47	19.7
	Others (Plastics, Wood)	62	25.9

Table 4.3. Regression Coefficients: Determinants of AMS Adoption.

Predictor Variable	B	Std. Error	β* (Std.)	t-value	Sig. (p)	Decision
(Constant)	0.645	1.254	—	0.514	0.608	—
Technological Factors (TF)	0.314	0.042	**0.345**	7.448	**<0.001*** **	**Reject H_{10}**
Organisational Factors (OF)	0.352	0.039	**0.415**	9.062	**<0.001*** **	**Reject H_{20}**
Environmental Factors (EF)	0.299	0.033	**0.413**	8.937	**<0.001*** **	**Reject H_{30}**

β* Ranking: OF (0.415) > EF (0.413) > TF (0.345). VIF values: TF=1.82, OF=1.76, EF=1.69 (all < 5; no multicollinearity concern). *** $p < 0.001$.

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Table 4.4. Simple Linear Regression Results: AMS Adoption Impact on Operational Performance

Performance Dimension	R	R^2	Adj. R^2	B (Unstd.)	β* (Std. = R)	t-value	F-stat.	p-value
Production Flexibility	0.671	0.450	0.448	*0.185*	**0.671**	13.91	193.60	**<0.001**
Manufacturing Lead Time	0.681	0.463	0.461	*0.182*	**0.681**	14.30	204.53	**<0.001**
Delivery Reliability ★	0.688	**0.474**	0.472	*0.179*	**0.688**	14.60	213.30	**<0.001**
Cost Efficiency	0.653	0.426	0.423	*0.165*	**0.653**	13.26	175.79	**<0.001**
Product Quality	0.683	0.466	0.464	*0.186*	**0.683**	14.39	207.09	**<0.001**

Note. B = unstandardised regression slope; β* = standardised regression coefficient. In simple linear regression with a single predictor, β* is mathematically equivalent to the model's Pearson correlation coefficient (R); accordingly, β* values shown equal the R values reported in column 2. All models significant at $p < 0.001$. ★ = Highest R^2 (0.474, Delivery Reliability). All β* > 0, confirming positive directional effects. H_{40} rejected for all five sub-dimensions.

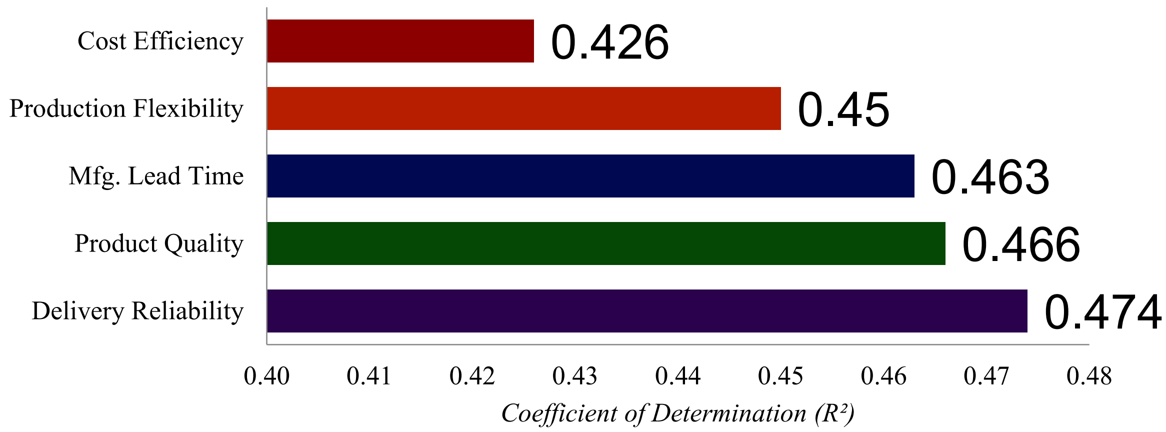

Figure 3. Variance Explained (R^2) by AMS Adoption across Five Operational Performance Dimensions

Figure 3 shows variance (R^2) by Agile Manufacturing Systems (AMS) adoption across five operational performance dimensions among manufacturing SMEs in Ogun State, Nigeria (n = 239). The x-axis is bounded between 0.40 and 0.48 to amplify inter-dimensional differences. All regression models are statistically significant at $p < 0.001$.

4.3 Drivers and Barriers to AMS Adoption

The drivers and barriers related to adoption of AMS are presented in Table 4.5 using descriptive statistics. All mean values are greater than 3.40 on a five-point scale, suggesting moderate impact and higher, while the low standard deviations (σ = 1.044-1.191) imply the presence of agreement between respondents. The primary driver of the adoption is the requirement for quicker customer response ($\bar{x}$=3.54), which corresponds to the increasing needs for fast order processing in the competitive manufacturing environment of Ogun State. The main barrier to the adoption is the high price of technologies ($\bar{x}$ = 3.57).

Table 4.5. Descriptive statistics of AMS adoption drivers and barriers

Item	Min	Max	Mean ($\bar{x}$)	Std. Dev. (σ)	Rank
DRIVERS OF AMS ADOPTION					
Need for faster customer response	2	5	**3.54**	1.106	**1st**
Desire to improve operational performance	2	5	**3.52**	1.044	**2nd**
Technological advancement in industry	2	5	**3.51**	1.130	**3rd**
Competitive market pressure	2	5	**3.46**	1.151	**4th**

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BARRIERS TO AMS ADOPTION					
High cost of technology (acquisition, installation, maintenance)	2	5	**3.57**	1.082	**1st**
Lack of skilled manpower and technical expertise	2	5	**3.48**	1.144	**2nd**
Poor infrastructure and unreliable power supply	2	5	**3.47**	1.129	**3rd**
Resistance to organisational change	2	5	**3.41**	1.191	**4th**

4.4 Integrative Discussion

The result demonstrating that organisational (β^* = 0.415) and environmental factors (β^* = 0.413) jointly serve as the most powerful predictors of adoption, both meaningfully exceeding technological factors (β^* = 0.345), is evidence supporting the Dynamic Capabilities framework: agility is inherently organisational and contextual rather than purely technological. The negligible difference between the organisational and environmental coefficients suggests these two domains operate as co-equal drivers rather than one dominating the other. Within SME settings characterized by resource limitations, managers' determination and the flexibility of employees could operate as substitutes for technology, ensuring that agility can be attained even in the absence of financial investments in automated technology. According to the Resource-Based View (RBV), organizational capabilities are far more enduring and difficult to imitate than tangible technologies due to being tacit, path-dependent, and socially constructed (Barney, 1991; Mohaghegh et al., 2024).

The close value of the two coefficients (0.413 for environmental and 0.415 for organizational factors) highlights the significance of environmental competitive pressures as well. Environmental factors that act as prime drivers of adoption include increasing customer requirements for speed ($\bar{x}$ = 3.54) and competition in the market ($\bar{x}$ = 3.46). This suggests that, just as much as SMEs seek to adopt agility for strategic reasons, there is a pull on them from outside forces that make such adoption unavoidable in a competitive environment. This process mirrors the competitive isomorphism mechanism described in institutionalism literature (Satyro et al., 2024).

Importantly, the finding that inadequate infrastructure (mean $\bar{x}$ = 3.47) and higher technology costs (mean $\bar{x}$ = 3.57) represent the key challenges, instead of attitudes towards innovation adoption (mean $\bar{x}$ = 3.41, which represents the least significant barrier), changes the nature of the problem from a problem of awareness and attitude to one of access and cost. This means that merely providing more information about the benefits of agile practices would be insufficient for solving the problem. Instead, interventions aimed at improving infrastructure and facilitating better financing terms are necessary if there is going to be successful diffusion of the agile manufacturing systems (AMS).

It can be argued that the observed ranking of variables in terms of their explanatory power makes sense – Delivery Reliability (R^2 = 0.474) > Product Quality (R^2 = 0.466) > Lead Time (R^2 = 0.463) > Flexibility (R^2 = 0.450) > Cost Efficiency (R^2 = 0.426). In particular, delivery reliability is explained best because agile practices help address the main causes of delivery problems such as inflexibility in schedule planning, slow responsiveness of suppliers, and quick resumption of operations after any disturbances. Energy and infrastructure costs are important determinants of cost efficiency that are partially independent of the rate of AMS adoption, especially within the high-tariff environment of Nigeria.

According to the Analysis of Variance (ANOVA), the size of the firm does not act as a moderator for the implementation of Agile Manufacturing Systems (AMS), given that η^2 = 0.001. This finding goes against the commonly held belief regarding the limited nature of agile manufacturing being available to only firms with ample resources. For small firms with fewer than 50 people, the ability to implement agile manufacturing systems will be enabled due to their inherent advantage of agility owing to simple structure, fast decision-making processes, clear lines of communication, and low organizational inertia despite having less resources. This observation is supported by the theoretical stand taken by (Manesh and Schaefer, 2010) and the findings of (Kumar et al., 2022). In light of this finding, the recommendation is clear. Any AMS campaign should be developed in an agnostic way that ignores firm size but considers the sectors' unique features instead.

The present findings are broadly consistent with comparable evidence from other developing economies. Kumar et al. (2022), examining 154 Indian manufacturing industries using PLS-SEM, found that agile manufacturing attributes explained 64.7% of variance in business performance (R^2 = 0.647), with Information Technology (β = 0.364) and Customer-Related Issues (β = 0.334) as the strongest predictors, ahead of Leadership Support (β = 0.142) and Human Resources (β = 0.133). The present study's comparable R^2 of 0.508 reflects a similar pattern, with organisational and environmental factors jointly dominant over technological factors, consistent with

Dynamic Capabilities Theory. The somewhat lower R^2 relative to (Kumar et al., 2022). likely reflects additional structural variance in the Nigerian SME context attributable to infrastructure deficits and financing constraints not captured in either model, reinforcing the case for contextually adapted AMS adoption frameworks in Sub-Saharan African settings (Aryeetey and Baffour, 2022).

Table 4.6 One-Way ANOVA Firm Size as Moderator of AMS Adoption

Firm Size	n	Mean AMA ($\bar{x}$)	Std. Dev.	ANOVA F	Sig. (p) / η^2
Small Enterprises (<50 employees)	143	19.83	2.63	0.190	$p = 0.663$ (ns), $\eta^2 = 0.001$
Medium Enterprises (50–199 employees)	96	19.98	2.44	—	—
Levene's Test: F = 0.670, p = 0.414 (variance homogeneity confirmed). η² = 0.001 (negligible; Cohen's benchmark for small effect: η² ≥ 0.01).					

4.5 Refining the TOE Framework

The obtained results provide ways of modifying the TOE theoretical approach that will increase its predictive validity concerning small businesses. The near-identical magnitudes of the organisational ($\beta^* = 0.415$) and environmental ($\beta^* = 0.413$) factors, both of which surpass the effect of technology ($\beta^* = 0.345$), suggest that the weights assigned to the three TOE dimensions cannot be equated. Rather than treating organisational factors as individually dominant, the evidence instead points to organisational and environmental constraints jointly outweighing technological readiness, with the TOE model requiring adjustment to reflect this two-domain dominance alongside the comparatively facilitating effect of technology. The weight of each TOE dimension is an empirical question and will have to be answered regarding the specifics of a particular institutional context.

4.6: Unexplained Variance and Omitted Variables

While the three-factor TOE model accounts for 50.8% of variance in AMS adoption, the remaining 49.2% suggests determinants beyond technological, organisational, and environmental factors as measured here likely shape adoption decisions. Plausible omitted variables include individual-level managerial risk orientation, which TOE's organisational construct captures only partially; direct access to formal credit and collateral, discussed contextually in this study's literature review but not separately operationalised as a predictor (Fanelli, 2021; Adegboye and Iweriebor, 2018); sector-specific technological intensity, given that the five sub-sectors sampled may differ in their inherent amenability to agile reconfiguration; and localised regulatory enforcement intensity, distinct from the general competitive pressure captured in the environmental construct. Future research incorporating these constructs may improve explained variance and refine understanding of AMS adoption determinants in Sub-Saharan African SME contexts.

5. Conclusion

This study provides the initial attempt at assessing factors associated with the adoption of AMS and their impact on operational performance using multiple variables in manufacturing SMEs in Ogun State. Organisational readiness and environmental drivers were found to have comparably strong, jointly dominant impacts on the decision to adopt AMS ($\beta^* = 0.415$ and 0.413, respectively), both well ahead of technological determinants ($\beta^* = 0.345$), in accordance with TOE conceptualisation. The process of adopting AMS led to considerable enhancements in all five dimensions of performance ($R^2 = 0.426$–0.474), while the structural barriers in the form of expensive technology ($\bar{x} = 3.57$) and knowledge deficiencies ($\bar{x} = 3.48$) prevailed over attitudinal barriers, indicating that the policy must focus on availability and accessibility issues. Firm size was confirmed to be a statistically insignificant moderator ($F = 0.190$, $p = 0.663$, $\eta^2 = 0.001$), suggesting the irrelevance of size criteria in the context of this study.

Limitations associated with methodology include the fact that there was no tracking of the number of questionnaires distributed per manufacturing subsector. This means that it is impossible to calculate the response rate per sector since only the total response rate (65.5%) and the composition of responses per sector could be calculated. Future research in this field should be designed to keep track of distributions in each sector and to establish the date on which registers were compiled. Notwithstanding this limitation, the findings yield several practical and policy implications worth highlighting.

Specifically, managers should consider developing organisational capabilities related to adaptability through leadership involvement, building up human capital, and implementing investments in scalable information technologies. The policy should focus on designing size-neutral incentive packages, establishing Technology Support Centres within the Ogun State industrial parks, and investing in electricity generation and telecommunications infrastructure. In addition, development banks should develop comprehensive programmes for financing SMEs' needs, comprising lease finance options, co-investment schemes, skills training, and AMS assessment prior to issuing loans.

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APPENDIX A

QUESTIONNAIRE

SECTION A: DEMOGRAPHIC AND FIRM PROFILE

1. Gender: ☐ Male ☐ Female

2. Age Group: ☐ Below 25 ☐ 25–34 ☐ 35–44 ☐ 45–54 ☐ 55 and above

3. Highest Educational Qualification: ☐ OND/NCE ☐ HND/BSc ☐ MSc/MBA ☐ PhD ☐ Others ___________

4. Current Position: ☐ Owner/Managing Director ☐ Production Manager ☐ Operations Supervisor ☐ Engineer ☐ Others __________

5. Firm Size: ☐ <50 ☐ 50–199

6. Years of Operation: ☐ Less than 5 ☐ 5–10 ☐ 11–20 ☐ Above 20

7. Manufacturing Sector: ☐ Food & Beverages ☐ Textiles & Garments ☐ Plastics & Rubber ☐ Metal/Fabrication ☐ Chemicals/Pharmaceuticals ☐ Furniture/Wood ☐ Others _________

SECTION B

TECHNOLOGICAL FACTORS (TF)

Scale: 1 = Strongly Disagree … 5 = Strongly Agree

Statement	1	2	3	4	5
Our firm has access to modern manufacturing technologies	☐	☐	☐	☐	☐
Existing production equipment supports flexible manufacturing	☐	☐	☐	☐	☐
ICT tools (ERP, CAD/CAM) are adequately used in operations	☐	☐	☐	☐	☐
New technologies are compatible with existing systems	☐	☐	☐	☐	☐
Technology cost is affordable for our firm	☐	☐	☐	☐	☐

ORGANIZATIONAL FACTORS (OF)

Scale: 1 = Strongly Disagree … 5 = Strongly Agree

Statement	1	2	3	4	5
Top management supports agile manufacturing initiatives	☐	☐	☐	☐	☐
Our organizational culture encourages flexibility and innovation	☐	☐	☐	☐	☐
Adequate financial resources are available for process changes	☐	☐	☐	☐	☐
Decision-making in our firm is fast and responsive	☐	☐	☐	☐	☐
Organizational structure supports cross-functional collaboration	☐	☐	☐	☐	☐

ENVIRONMENTAL FACTORS (EF)

Scale: 1 = Strongly Disagree … 5 = Strongly Agree

	Statement	1	2	3	4	5
	Customer demand is highly unpredictable	☐	☐	☐	☐	☐
	Competitive pressure forces us to adopt flexible practices	☐	☐	☐	☐	☐
	Government policies support manufacturing innovation	☐	☐	☐	☐	☐
	Infrastructure availability influences technology adoption	☐	☐	☐	☐	☐
EF5	Market changes require rapid operational response	☐	☐	☐	☐	☐

AGILE MANUFACTURING ADOPTION (AMA)

Scale: 1 = Strongly Disagree … 5 = Strongly Agree

Statement	1	2	3	4	5

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Our firm quickly responds to changes in customer demand	☐	☐	☐	☐	☐
Production processes are easily reconfigured	☐	☐	☐	☐	☐
We can rapidly introduce new or modified products	☐	☐	☐	☐	☐
Cross-functional teams are used in production planning	☐	☐	☐	☐	☐
Information flows freely across departments	☐	☐	☐	☐	☐

OPERATIONAL PERFORMANCE (OP)

Scale: 1 = Strongly Disagree … 5 = Strongly Agree

Statement	1	2	3	4	5
Our production costs have reduced over time	☐	☐	☐	☐	☐
Product quality meets customer expectations consistently	☐	☐	☐	☐	☐
On-time delivery performance has improved	☐	☐	☐	☐	☐
Our firm has become more flexible in meeting market needs	☐	☐	☐	☐	☐
Manufacturing lead time has reduced	☐	☐	☐	☐	☐

DRIVERS OF AGILE MANUFACTURING ADOPTION

Scale: 1 = Strongly Disagree … 5 = Strongly Agree

Statement	1	2	3	4	5
Need for faster customer response	☐	☐	☐	☐	☐
Competitive market pressure	☐	☐	☐	☐	☐

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Desire to improve operational performance	☐	☐	☐	☐	☐
Technological advancement in the industry	☐	☐	☐	☐	☐

BARRIERS TO AGILE MANUFACTURING ADOPTION

Scale: 1 = Strongly Disagree … 5 = Strongly Agree

Statement	1	2	3	4	5
High cost of technology	☐	☐	☐	☐	☐
Lack of skilled manpower	☐	☐	☐	☐	☐
Resistance to organizational change	☐	☐	☐	☐	☐
Poor infrastructure and power supply	☐	☐	☐	☐	☐