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ORIGINAL ARTICLE

Effect of advanced manufacturing technology, concurrent engineering of product design, and supply chain performance of manufacturing companies

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Abstract As competition shifts away between competitors to supply chains, simultaneous sharing of technical expertise on product design is key to manufacturing success. Thus, purpose of this study is to examine the mediating effect of concurrent engineering of product design (CEPD) on the relationship between advanced manufacturing technology (AMT) and supply chain performance (SCP). The paper is a cross-sectional study, and data was collected among top managers of manufacturing companies. Cluster and systematic random sampling techniques were used to select the respondents. Structural equation modeling (Amos graphic) was used for analysis. The study found a positive relationship between advanced manufacturing technology and supply chain performance, advanced manufacturing technology and concurrent engineering of product design, and concurrent engineering of product design and supply chain performance. It also concluded that concurrent engineering of product design is a full mediator between advanced manufacturing technology and supply chain performance.

Keywords Advanced manufacturing technology · Concurrent engineering of product design · Supply chain performance · Manufacturing companies

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1 Introduction

The concept of concurrent engineering (CE) emerged out of Japanese management philosophy and popularized in the West in the 1970s [1]. Concurrent engineering of product design (CEPD) is a topical area of manufacturing strategy as companies have realized that supply chain “begins on the drawing board” ([2, 3]). Once a product is designed and prototyped, at least 80% of its cost, quality, and life cycle are determined [4]. Thus, the possibility of failure and tendency for rework decreases [5]. As such integration between focal companies and suppliers of advanced manufacturing technology (AMT) on product design is essential. Several issues motivate this study. First, there is dearth of studies on how AMT influence CEPD. Although, previous studies have investigated AMT with firm performance [6], how it integrates and relates with CEPD, and supply chain performance (SCP) is less reported in the literature ([7, 8]).

Secondly, studies on advanced manufacturing technology focus more on its technical aspect while ignoring the human side [9]. Literature points that the implementation of AMT is both computer and human-driven [10]. Third, failure to share technical information between focal companies and AMT suppliers has been identified as a major obstacle in product design [11]. Therefore, there is need to improve technical collaboration between focal companies and AMT manufacturers [12]. Fourth, while previous studies about AMT examine buyer-seller pre-purchase relationship [13], few studies examine the relationship at post-purchase stage [6].

Lastly, there are inconsistent findings on the relationship between AMT and SCP. For instance, significant relationship was found between AMT and SCP [14]. Nevertheless, Nair et al. [15] argue that the application of hard manufacturing technology by medium firms increases lead-time. Gunasekaran [16] suggested that AMT alone does not

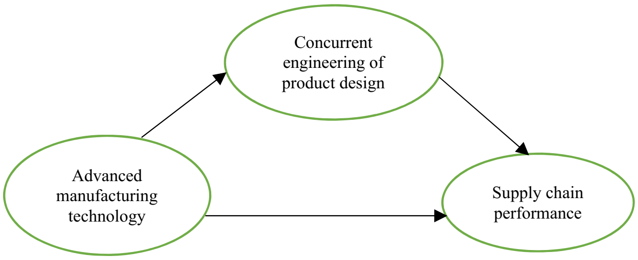

Fig. 1 Research framework

influence customer responsiveness and market performance. Furthermore, most firms are dissatisfied with AMT investment due to high rate of failure [17]. The inconsistencies in the research findings and problems with AMT investment propel the need for further debates on how to improve AMT implementation [18]. In order to cover the gaps, the paper investigates the intervening role of CEPD on the relationship between AMT and SCP.

AMT is defined as “a group of computer-based technologies, which includes computer-aided design, computer-aided manufacturing, manufacturing resources planning, robotics, group technology, flexible manufacturing systems, automated materials handling systems, computer numerically controlled (CNC) machine tools, and bar-coding or other automated identification techniques and any technology, which is new or advanced to a company when compared to its previous or

Table 1 Organizational data

Company data		Frequency	Per cent
Sector	Food, beverages, and tobacco	54	19.6
	Chemicals and pharmaceuticals	61	22.2
	Domestic and industrial plastic, rubber, and foam	34	12.4
	Basic metal, iron and steel, and fabricated metal products	29	10.5
	Pulp, paper and paper products, printing and publishing	27	9.8
	Electrical and electronics	17	6.2
	Textile, wearing apparel, carpet, leather/leather footwear	22	8.0
	Wood and wood products including furniture	16	5.8
	Non-metallic mineral products	8	2.9
	Motor vehicle and miscellaneous assembly	7	2.5
Job title	Vice president and above	72	26.2
	Director/assistant director	57	20.7
	Manager/assistant manager	146	53.1
Ownership structure	Foreign-owned company	78	28.4
	Local firm	153	55.6
	Foreign-local firm	44	16.0
Firm age	1–5 years	27	9.8
	6–10 years	49	17.8
	11–20 years	50	18.2
	21–30 years	66	24.0
	31 years or more	88	30.2
Number of employees	100 or less	62	22.5
	101–200	45	16.4
	201–500	73	26.5
	501 or more	95	.5
Annual revenue	10 or less million	60	21.8
	11–100 million	38	13.8
	101–999 million	46	16.7
	1–30 billion	122	44.4
	31 or more billion	9	3.3
Annual cost	10 or less million	67	24.4
	11–100 million	37	13.5
	101–999 million	56	20.4
	1–30 billion	105	38.2
	31 or more billion	10	3.6

Table 2 Results of confirmatory factor analysis (CFA) and reliability

Variable	No. of items/ dimensions	Cronbach's Alpha (>0.70)	Validity (CFA)
Advanced manufacturing technology	6/2	0.867	GF1=0.984; AGFI=0.958; CFI=0.993; TLI=0.988; NFI=0.985; Chisq/df=1.751; RMSEA=0.051; PCLOSE=0.425
Concurrent engineering of product design	4/1	0.816	GF1=0.996; AGFI=0.980; CFI=0.999; TLI=0.997; NFI=0.994; Chisq/df=1.210; RMSEA=0.027; PCLOSE=0.520
Supply chain performance	9/3	0.832	GF1=0.963; AGFI=0.928; CFI=0.971; TLI=0.955; NFI=0.948; Chisq/df=2.182; RMSEA=0.064; PCLOSE=0.520; P-Value=0.001

GF1, AGFI, CFI, TLI, NFI indexes (must be >0.9), Chisq/df (must br <3.0), RMSEA (must be <0.08), PCLOSE (must be >0.05)

current manufacturing technology" ([19, 13]). The benefits of AMT in the supply chain include transformation of raw materials, upstream and downstream collaboration [20], cost reduction, and product quality [6]. Therefore, AMT influences competitive advantage and firm performance [18].

CE is the foundation of product development process [21]. It is defined as a manufacturing philosophy where manufacturers, suppliers, designers, marketers, and customers work concurrently right from the design of a product to its market success [1, 22]. According to Crestani et al. [23], CEPD consumes less than 5 % of product development cost but reduces more than 70 % of its final cost. Once a product is designed and prototyped, at least 80 % of its cost, quality, and life cycle are determined [3]. Thus, the possibility of product failure and tendency for rework decreases [5].

1.1 Research framework and hypotheses development

This study is influenced by the social exchange theory [24]. The theory is concerned with the process of mutual reward as a result of exchanges and transaction [25]. In this study, CE is a collaborative process that brings AMT manufacturers, focal companies, and major buyers into technical collaboration and information sharing. CE influences relational norms, trust, and reward sharing among partners. The interaction will decline or terminate if it is not mutually rewarding. Thus, AMT implementation is an antecedent of CEPD [26], and SCP is an outcome of AMT [14] and CEPD [27]. Based on the social exchange theory and the prevailing literature, we developed the research framework in Fig. 1.

1.2 Hypothesis development

1.2.1 AMT and supply chain performance

AMT is a solution for firms' competitiveness [28]. Yet, incidence of technology paradox shows that AMT implementation causes minor rather than major improvement in firm performance [29]. On top of that, most Nigerian manufacturers underutilize AMT due to lack of expertise and poor collaboration with AMT manufacturers. Therefore, there is need to integrate AMT implementation with the human element of CEPD. Although Sha et al. [14] suggest significant relationship between AMT and supply chain performance, Dıaz et al. [30] concluded that there is no difference in the performance of companies implementing higher and lower level of automation. As product design requires teamwork and information sharing, CEPD provides engineering knowledge to help achieve close-loop product development ([23]; [31, 32]. Based on the need for technical collaboration between focal companies and AMT manufacturers, it is hypothesized that:

> H1: There is a significant relationship between AMT and SCP.
> H2: There is a significant relationship between AMT and CEPD.

1.3 Concurrent engineering and supply chain performance

Competition is no longer between businesses but between the supply chains, and firms have acknowledged that technical collaboration is essential for competitive advantage and performance [33]. Developing right product the first time is

Table 3 Mean, standard deviation, constructs correlation, composite reliability, and average variance extracted

Variable	Mean	Std. Dev.	AMT	CEPD	SCP	CR	AVE
AMT	28.6754	7.43379	1.000	*0.088*	*0.037*	0.923	0.668
CEPD	20.3571	3.97837	.296**	1.000	*0.118*	0.820	0.539
SCP	53.7183	4.35306	.193**	.343**	1.000	0.924	0.577

AMT advanced manufacturing technology, *CEPD* concurrent engineering of product design, *SCP* supply chain performance, *CR* composite reliability, *AVE* average variance extracted

[a] Values in italics are the squared correlation and are less than AVE of all constructs

[b] Indicates Pearson correlation is significant at the 0.01 level (2-tailed)

Table 4 Direct relationship of AMT and SCP

MODEL 1		Standardized estimates		Unstandardized estimates				
X→Y)	Relationship	Std. beta	R^2	Actual beta	S.E.	C.R.	*P*	Remark
	AMT and SCP	.28	.08	.09	.037	2.489	.013	Significant

Std beta standardized beta, R^2 coefficient of determination, *actual beta* nstandardized beta, *S.E.* standard error, *C.R.* critical ration, ***=probability value and significant at $P<0.001$

essential for firm success and CE is the key. CE helps the supply chain achieve close-loop product development processes [34]. Previous studies show that the relationship between CEPD and SCP increases customer responsiveness [20, 35], firm competitiveness, and performance [36]. CE improves product development time [37], product quality [27], inventory, and labor costs [38]. Similarly, Pero et al. [39] point that product development fail if it is not supported by product design. However, Lo and Power [40] did not find significant relationship between product design and supply chain efficiency and responsiveness. Furthermore, CE is not as efficient as silo product design and development ([41]. Based on the social exchange theory and inconsistent arguments above, it is postulated that:

H3. There is a significant relationship between CEPD and SCP.

1.4 AMT and SCP in the presence of CEPD

The purpose of supply chain management is to ensure that the transformation, flow of goods, and information are cost-efficient and customer-responsive [42]. This requires an innovative design of the supply chain. A responsive supply chain uses AMT to improve time-to-market, lead-time, cost, flexibility, and quality performance [43]. Khan et al. [36] argue that collaborative product design influences firms' resiliency, responsiveness, market position, and competitive advantages. Similarly, AMT implementation influences CE [44]. An evaluation of traditional sequential method of new product development shows that 50–80 % of products under sequential method are not delivered on time [4]. Since a significant relationship is found between AMT and SCP, CEPD and SCP, and AMT and CEPD, we argue that the role of CEPD could influence the relationship between AMT on SCP. Therefore, it is hypothesized that:

H4: CEPD mediates the relationship between AMT and CEPD.

1.5 Methods and measurement

The study is based on the epistemological and ontological paradigm of the post-positivism worldview and the methodology of cross-sectional survey [45]. Cluster and random sampling was used to distribute 323 to top managers of Nigerian manufacturing of which 292 were completed and returned. Two hundred eighty-six were found usable for analysis. The questionnaires were distributed between August 2014 and November 2014. Measurement of AMT was adopted from Burgess and Gules [46] and Koc and Bozdag [47]; CEPD was adopted and modified from Koufteros et al. [48]; and SCP was selected from Cirtita and Glaser-segura [49]. Data was analyzed using IBM SEM (Amos) 21.0.

2 Results

2.1 Descriptive analysis

The organizational data is presented in Table 1. The table reports the frequency and percentage of responses of the questionnaires.

2.2 Validity and reliability

Based on the analysis of the measurement and structural models, the minimum threshold of Cronbach's alpha of 0.70

Table 5 Mediating relationship of CEPD on AMT and SCP

MODEL 2		Standardized estimates		Unstandardized estimates				
(X→Y,	Relationship	Std. beta	R^2	Actual beta	S.E.	C.R.	P	Remark
X→M,	AMT and CEPD	.35	.18	.25	.068	3.648	***	Significant
M→Y)	CEPD and SCP	.34		.15	.040	3.728	***	Significant
	AMT and SCP	.16		.048	.028	1.728	.084	Non-significant

Std beta standardized beta, R^2 coefficient of determination, *actual beta* unstandardized beta, *S.E.* standard error, *C.R.* critical ration, ***=probability value and significant at $P<0.001$

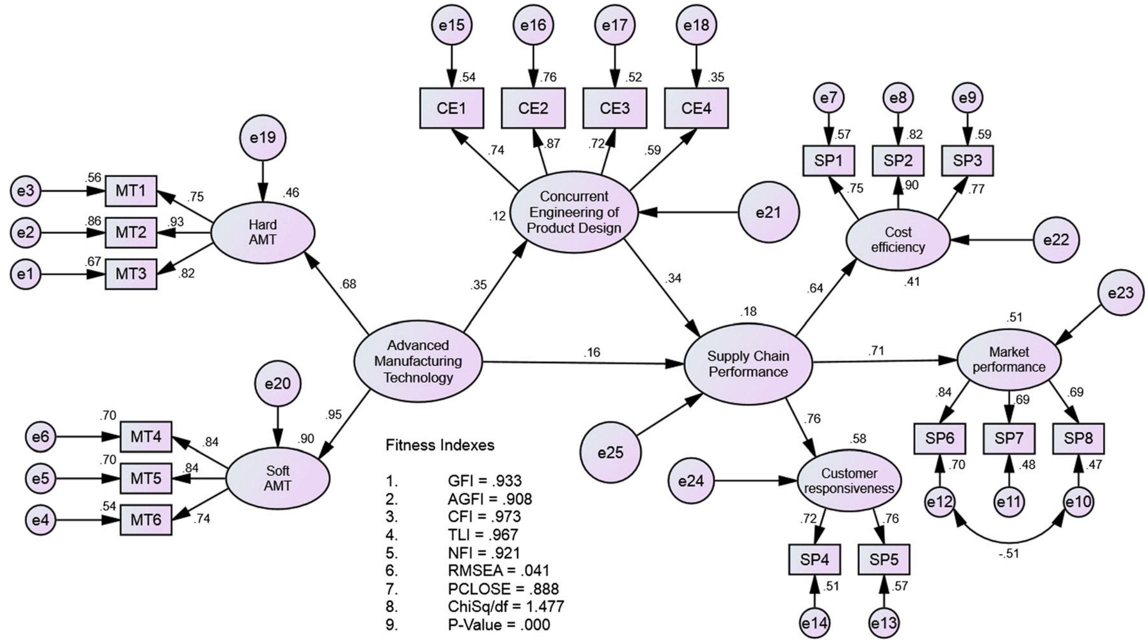

Fig. 2 Structural model

was achieved. The Cronbach's alpha in Table 2 ranges between 0.816 and 0.867. Table 2 also shows that unidimensionality of measurement has been satisfied, and all the latent variables have acceptable goodness-of-fit indices. Furthermore, confirmatory factor analysis (CFA) i.e., convergent and discriminant validities were assessed based on the four guidelines suggested by Hair et al. [50]. These conditions are (i) factor loading of each items on the construct must be ≥0.5, (ii) composite reliability of construct must be ≥0.7, (iii) average variance extracted (AVE) of each construct must be ≥0.50, and (iv) AVE of each construct must be more than the squared value of its correlation with all other constructs. These conditions are analyzed in Table 3 and both convergent and discriminant validities exist.

2.3 Hypothesis testing

The hypotheses in this study are tested based on the four-stage mediation conditions of Baron and Kenny [51] and Mathieu and Taylor [52]. The stages are (i) direct relationship between X and Y must be positive and significant, (ii) the relationship between X and M must be positive and significant, (iii) the relationship between M and Y must be significant, and (iv) partial mediation occurs if product of X→M and M→Y paths is greater than the significant X→Y path. Full mediation occurs if X→M and M→Y paths are positive and significant while the X→Y becomes insignificant when a mediator is introduced in a model. Prior to the structural model, a direct relationship (X→Y) was tested, and result shows that the relationship between AMT and SCP is positive and significant (β=.28, r=.08, P<.005). This result is shown as model 1 in Tables 4 and 5, and Fig. 2 shows that the relationship between AMT and CEPD (β=.35, r=.25, P<.001) as well as CEPD and SCP (β=.34, r=.15, P<.001) is positive and significant. The goodness of fit indices of the structural model are satisfactory as GFI, AGFI, CFI, TLI, NFI >.90, RMSEA <.6, PCLOSE is non-significant, ChiSq/df <3.000, and P is significant.

3 Discussion

Table 5 shows that when AMT goes up by 1, CEPD goes up by .25. The probability of getting a critical ratio as large as 3.648 in absolute value is less than .001. In other words, the regression weight for AMT in the prediction of CEPD is significantly different from zero at the .001 level (two-tailed). Likewise, when CEPD goes up by 1, SCP goes up by .15. The probability of getting a critical ratio as large as 3.728 in absolute value is less than .001. In other words, the regression weight CEPD in the prediction of SCP is significantly different from zero at the .001 level (two-tailed). Additionally, when AMT goes up by 1, SCP goes up by 0.048. The probability of getting a critical ratio of 1.728 in absolute value is .084. In other words, the regression weight for AMT in the prediction of SCP is not significantly different from zero at the .05 level (two-tailed).

Result of the mediating effect is extracted from Fig. 2 and Table 5. The finding shows that CEPD is a full mediator between AMT and SCP. This is because the introduction of CEPD into model 2 changed the X→Y relationship in model 1 (β=.28, r=.08, P<.05) into non-significant (β=.16, r=.048, P>.005). The X→M and M→Y paths remain positive and significant at (β=.35, r=.25, P<.001) and (β=.34,

r=.15, P<.001), respectively. The test of H1 in Table 4 shows that AMT has significant relationship with SCP. This finding is consistent with Das and Nair [6] and Dıaz et al. [30]. The test of H2 suggests that the relationship between AMT and CEPD is significant. This finding is similar to Pandza et al. [44] who suggest that AMT influences CE. Furthermore, H3 which postulates a significant relationship between CEPD and SCP is also positive and supported. These findings are consistent Crestani et al. [23] who found that CEPD consumes less than 5 % of product development cost but reduces more than 70 % of products' final cost. Similarly, Aravindan and Punniyamoorthy [38], Tseng and El-Ganzoury [27], and Wei [37] suggested that CE improves product development time, product quality, inventory and labor costs, customer responsiveness, and firm competitiveness. For H4, a full-mediating effect of CEPD on the relationship between AMT and SCP was found. To the best of our knowledge, this is the first stream of research on these variables and a major contribution of this paper.

4 Conclusion and suggestion for further studies

This paper highlights the importance of integrating CEPD into the field of AMT to improve SCP. There are three theoretical contributions of this paper. First, the paper is the first to develop a research framework with CEPD as a mediator on the relationship between AMT and SCP. Therefore, the study extends the literature of supply chain management in the perspective of engineering and human relation. Second, the mediating effect of CEPD indicates three inferences. One, CEPD could resolve the mixed findings on the relationship between AMT and SCP. Two, AMT must influence CEPD to enhance SCP. Three, AMT is not an isolated capability and therefore must be complemented with human capability. Thus, AMT productivity paradox could be explained through simultaneous technical collaboration between focal companies and AMT manufacturers at the product design stage. Additionally, by testing the social exchange theory on AMT in a supply chain management framework, the paper demonstrates the importance of boundary spinning of engineering capability and social (human) process to improve organizational performance. Lastly, the robustness of the methodology contributes to the epistemology and ontology of the post-positivism worldview.

For practical purpose, the study could guide the strategic behaviors of top level managers of manufacturing companies to promote technical collaboration on product design and development with AMT manufacturers. The research is also important to manufacturers of AMT. Through the collaborative processes, AMT manufacturers could understand the difficulties companies face with technology implementation. As such they could plan and redesign future technologies which are firm-specific and user friendly. Similarly, technical collaboration between focal companies and AMT manufacturers could enhance their agility, customer responsive, profitability, and mutual benefits. Similarly, the participation of AMT manufacturers in product design will enhance their goodwill and reputation, which thus affects long-term business relationship and profitability. At the functional level, supply chain managers, production managers, and marketing managers could utilize the findings of this study to coordinate product design and development strategies. Although the study has important findings, it has some inherent limitations. First, there is need to investigate the impact of information technology with concurrent engineering and supply chain performance. Second, the study needs to be replicated in small-scale companies and service industry within the Nigerian economy. There is need to also extend the replication into manufacturing and service industries of developing economies such as Malaysia, South Africa, and Argentina.

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