Journal of Namibian Studies, 34 S2(2023): 592-607 ISSN: 2197-5523 (online)

Developing and Validating Measurement for Manufacturing Flexibility Implementation Strategies: The PLS-SEM Approach

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Abstract

Manufacturing flexibility (MF) has been acknowledged as tool to help manufacturers adapting to uncertainty in the business environment. Fluctuating market demand, rapid technological changes, shorter product life cycles and increase level of customization are among the caused that create uncertainties in the market. However, manufacturers are facing great challenge to reap the real benefit from implementing manufacturing flexibility. Therefore, this study aimed to investigate the contributing factors that can enhance manufacturing flexibility implementation in mass customization production strategy among manufacturing firms in Malaysia. An extensive review on manufacturing flexibility literature and content validity assessment were conducted with industry practitioners and academicians. Four MF constructs and 16 measurement items have been identified from the review. A complete set of questionnaires have been developed by adopting, adapting, or self-develop based on the extensive literature review. This research study has recognized reliable MF constructs, consisting of four MF constructs and 16 measurement items. Thus, this study can be used to help identify provide method to enhance MF implementation at the manufacturing firm's level. This study provided a useful tool for researchers to gain a greater knowledge and understanding on MF implementation. It acts to bridge the inadequacy of related studies on manufacturing flexibility by using the T-O-E framework. For practitioners, it is useful to review back the effectiveness of the usage of their internal resources in overcoming uncertainties in the environmental factors. More significantly, practitioners should be able to adopt the MF practices in a more holistic way. This study is among the first attempt to develop MF constructs for evaluating the enhancement of MF implementation in Malaysia.

Keywords: Manufacturing Flexibility, Constructs, Uncertainty, Globalization

Introduction

Numerous challenges are faced by the manufacturing firms that is due to the globalization issues. Among the challenges includes fluctuating market demand, rapid technological changes, shorter product life cycles and increase level of customization. As a result, manufacturers are forced to make the necessary improvement to their current business operations (Abolghasemi et al., 2020; Harsch & Festing, 2020). Often innovation is considered as one of the most important factors for an organization's success, growth, and survival. Despite that, manufacturers are facing internal hinderance in executing innovation activities due to resource and budget constraint (Dziallas, 2020). Furthermore, lack of market knowledge and increase business complexity have impede innovation work (Sadeh & Dvir, 2020). Such market environment are forcing manufacturing firms to build some form of flexibility into their business process (Buckley, Craig, Mudambi, 2019).

Even though manufacturing flexibility is often regarded as an adaptive response to environmental uncertainty, many manufacturers firms are still facing tremendous challenges to remain flexible (Fragapane et al., 2020; Jain et al., 2013). Many manufacturing firms are finding the difficulties to implement manufacturing flexibility and achieve it real benefit (Frank et al., 2019; Harsch & Festing, 2020; Mishra et al., 2018). Recognizing the contributing factors that contribute to manufacturing flexibility implementation would be essential for managers to avoid futile development efforts.

Lack of studies that empirically seek to identify what contribute to an effective implementation of manufacturing flexibility have affecting manufacturing flexibility development (Mishra, 2021; Mishra et al., 2018). Even if there is, those research works are based on a single-item measurement measure based on different flexibility dimensions (Jain et al., 2013; Sushil, 2018; Vokurka & O'Leary-Kelly, 2000). In addition, manufacturing firms are facing the difficulties to effectively integrate their manufacturing technologies, leaving them with the failure to attain the expected business performance (Aversa et al., 2021). These shortcoming are causing the manufacturing firm to implement manufacturing flexibility in an unsystematic way and produce very low return towards the improvement result (Dalenogare et al., 2018; Marcon et al., 2022). Importantly to note here is that implementing manufacturing flexibility initiative is not as easy as plugged-in task since its effectiveness is also influences by a number of other multi-dimensional factors.

There is an urgent need to develop and validate the integrated and comprehensive MF constructs. Therefore, the main objective of this study is to develop and validate measurement for MF implementation in mass customization production strategy in Malaysia. This study is important as practitioners can gain a more rigorous knowledge that can equip them towards implementing manufacturing flexibility systematically. In addition, it will enable manufacturers to execute their manufacturing process effectively and efficiently. In addition, the measurement items developed in this study can be used to assess and justified whether the practices applied by the firms are effective or need further improvement. The definition and basic concept of MF, as well as the development of MF practices are discussed in this study. Subsequently, the contributing factors and the development of the constructs will be discussed in the study. Findings and implications of the study will be examined and concluded with limitation and suggestion for future research.

Manufacturing Flexibility Concept

Manufacturing flexibility is a concept that emerged in the early 1980s which allows a certain level of adaptability to be implemented to react to changes. Often manufacturing flexibility concept involves firms' endless efforts to deal with slightly or greatly fluctuating in customer requirements and market orientation (Mishra, 2020). Such fluctuation could be triggered by many factors such as fierce competition, market volatility, and change in customers preferences.

Flexibility is a complex term which can give different meaning depending on the contexts and adaptation needs based on what happened in the environment (Jain et al., 2013; Ojstersek & Buchmeister, 2020). Various researchers in the past have attempted to define the term manufacturing flexibility. For example, manufacturing flexibility is defined as the system ability to react to the environmental uncertainties (internal and external) effectively and efficiently to produce high quality products at a competitive price (A. Jain et al., 2013). Based on this definition, manufacturing flexibility requires a manufacturing strategy that emphasis on maintaining a lean and dynamic operation to align the internal manufacturing flexibility with the constraints posted by the external environment.

Manufacturing flexibility is often regarded as situation specific which requires different level of manufacturing flexibility for different kind of uncertainties (Ojstersek & Buchmeister, 2020). This could means which manufacturing flexibility dimension a company will adopt is very much depending on the source of environmental instability it faces or expects to face. Such multi-dimensional nature of manufacturing flexibility was agreed by past researchers who have classified manufacturing flexibility into various sub-dimensions such as labor flexibility, machine flexibility, routing flexibility, material-handling flexibility, and volume flexibility (D'Souza & Williams, 2000; Gerwin, 1987; Slack, 1983; Upton, 1994).

Developing the Constructs

In a quantitative research, constructs are the abstract idea, complex and not directly observable that the researcher can define in conceptual terms but cannot be directly measured (Hair et al., 2014). Construct are considered latent variable since they cannot be directly measured but must be approximately measured using multiple indicators. Constructs can be classified into two types: higher-order construct and lower-order construct. The higher-order construct provides a framework for researchers to model a construct to confirm that the theorized construct in a study loads into a certain number of underlying lower-order constructs. Indicators (also known as measurement items or manifest variables) are the observed value of a variable that measure a construct that is typically used in quantitative research.

For MF implementation is to perform well, some contributing factors or elements must take place. In this research, the author has applied the Technology-Organization-Environmental (T-O-E) framework to come out with the contributing factors. The T-O-E framework outline three elements that can influence readiness factors towards adoption of new innovation at the organizational level: Technological context, the organizational context, and the environmental context (Al-Hujran et al., 2018; Chatterjee et al., 2021; Mabad et al., 2021). In this research the technological context is represented by smart manufacturing technology. The organizational factors by top management commitment and team-based work culture. The environmental context is represented by the competitive intensity and market turbulence.

Smart manufacturing technology

The smart manufacturing technology were regrouped based on past studies that discussed on how smart technology improve manufacturing flexibility implementation. The result is as exhibited in Table 1.

Table 1: Smart Manufacturing Technology

Types/ dimensions	Literature support
Big Data Analytics	1, 2, 3, 8, 9, 10, 18, 19
Augmented Reality (AR)	4, 5, 6, 7, 8, 9, 11, 19
Internet Of Things (IoT)	8, 9, 10, 12, 13, 14, 19, 20
Cloud Computing	8, 10, 14, 15, 16, 17, 18, 19, 20
Vertical and Horizontal System Integration	14, 19
Additive Manufacturing	19
Autonomous Robots	7, 8, 9, 19

Note: [1] Cronin et al. (2019), [2] Peruzzini et al. (2017), [3] Hernandez-de-Menendez et al. (2020), [4] Martínez et al. (2014), [5] Fruend & Matysczok (2002), [6] Damiani et al. (2018), [7] Moreno et al. (2017), [8] Simons et al. (2017), [9] Schuh et al. (2014), [10] Wei et al. (2017a) [11] Shao et al. (2015), [12] Zhong et al. (2017), [13] Jeschke et al. (2017), [14] Thoben et al. (2017), [15] Yu et al. (2015), [16] Kagermann (2015), [17] Zhang et al. (2010), [18] Gao et al. (2015), [19] Narula et al. (2020), [20].

Organizational factors

Organisational context is related to the resources and the characteristics of the firm such as organization size, managerial structure operational attributes or conditions within an organization (Alshamaila et al., 2013). It could also mean the ability of the organization to adapt and adjust to the changing demand needs exerted by the market environment. Table 2 shows the organizational factors and its indicators that influence manufacturing flexibility implementation based on the past literature report.

Table 2: Organizational factors

Types/ dimensions	**Literature support**
Top Management Commitment	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Team-based work culture	3, 7, 10

Note: [1] Fisel et al. (2019), [2] Llopis-Albert et al. (2019), [3] Small & Yasin (1997) [4] Altay et al. (2018), [5] Forés & Camisón (2016), [6] Eckstein et al. (2014), [7] Battisti et al. (2019), [8] Ponomarov & Holcomb (2009), [9] Tang (2006), [10] Meyer et al. (2002).

Environmental factors

Over the years, many manufacturing companies are facing increasing challenges as the market environment are becoming more competitive due to the changes in the customer’s requirement and demand. These changes can sometime create additional complexity and uncertainty in the market environment. Table 3 display the environmental factors that can influence the implementation of manufacturing flexibility in an organization.

Table 3: Environmental factors

Types/ dimensions	**Literature Support**
Market Turbulence	1, 2, 3, 4, 5, 6, 7
Competitive Intensity	8, 9, 10

Note: [1] (Seebacher & Winkler (2014), [2] Taques e,t al. (2020), [3] Zhao et al. (2018), [4] Enkel et al. (2005), [5] Mishra & Shah (2009, [6] Singh & Power (2009), [7] Feng et al. (2012), [8] Carlos Hernández-Carrión et al. (2016), [9] Ndubisi et al. (2020), [10] Chesbrough (2003).

Manufacturing flexibility

Which dimension of manufacturing flexibility that a company will adopt is very much depends on the source of environmental instability it faces or expects to face. The works of past researchers during the period of 1984 to 2020 regarding manufacturing flexibility dimensions has been summarized in Table 4.

Table 4: Manufacturing flexibility

Types/ dimensions	Literature Support
Machine Flexibility	1, 3, 4, 5, 6, 9
Routing Flexibility	1, 2, 3, 4, 5, 6, 9, 10
Volume Flexibility	1, 2, 3, 4, 5, 6, 7, 8, 9
Material Handling	3, 4, 5, 8, 9, 10
Labor Flexibility	5, 9, 10

Note: [1] Browne et al. (1984), [2] Gerwin (1987), [3] Sethi and Sethi (1990), [4] Gupta and Somers (1996), [5] Koste & Malhotra (1999), [6] Chen and Adam (1991), [7] Slack (1987), [8] D'Souza and Williams (2000), [9] Tan and Lim (2019), [10] Sawhney (2006).

Methodology

A survey approach using a set of a close-ended questionnaire with ordered choice questions was used to gather the data. Each measurement item was adopted, adapted, or self-developed from several sources from the past research studies. A multiple endpoints Likert scale was used to measure the construct consists of smart manufacturing technological factors, organizational factors, environmental factors, and manufacturing flexibility. The Likert scale endpoints ranging between five, six, and seven-point and were chosen since it can give a more valid and reliable result (Krosnick & Fabrigar, 1997). Likert scale descriptors used in this study stretching from strongly disagree until strongly agree.

The unit of analysis for this study is organization. The sampling frame comprises of manufacturing firms who are members of the Federation of Malaysian Manufacturers (FMM). A cluster random sampling method were employed in subsectors involving electrical and electronics, textile and apparel, transport equipment & technology, wood-based Industry, and machinery and metal Industry A total of 1185 companies have been identified as using the discrete manufacturing process within those clusters. 1000 sets of questionnaires were sent to the respondent email address as mentioned in the FMM directory. Demographic results are shown in Table 5.

Table 5: Demographic of the Respondent Companies

Demographic	Count	Percent
Nature of Business		
Electrical and Electronic	54	37.2
Machinery and Metal Industry	33	22.8
Textiles and Apparels	2	1.4
Transport Equipment	37	25.5
Wood-based Industry	19	13.1
Company Ownership		
Foreign invested enterprise	64	44.1
Government linked company	11	7.6
Local and foreign joint venture	19	13.1
Local private enterprise	41	28.3
State owned company	10	6.9
Position in the Company		
President/ CEO/ MD	3	2.1
Operation General Manager	22	15.2
Engineering General Manager	7	4.8
Operation Manager	45	31
Engineering Manager	12	8.3
Operation Executive	37	25.5
Engineering Engineer	19	13.1

A total of 155 questionnaires were received out of the 1000 questionnaires, leaving a response rate of 15.5%. However, 10 responses were dropped as the respondent firms since they did not answer discrete manufacturing as their manufacturing process. Therefore, only 145 questionnaires were used in this study.

Result and Discussion

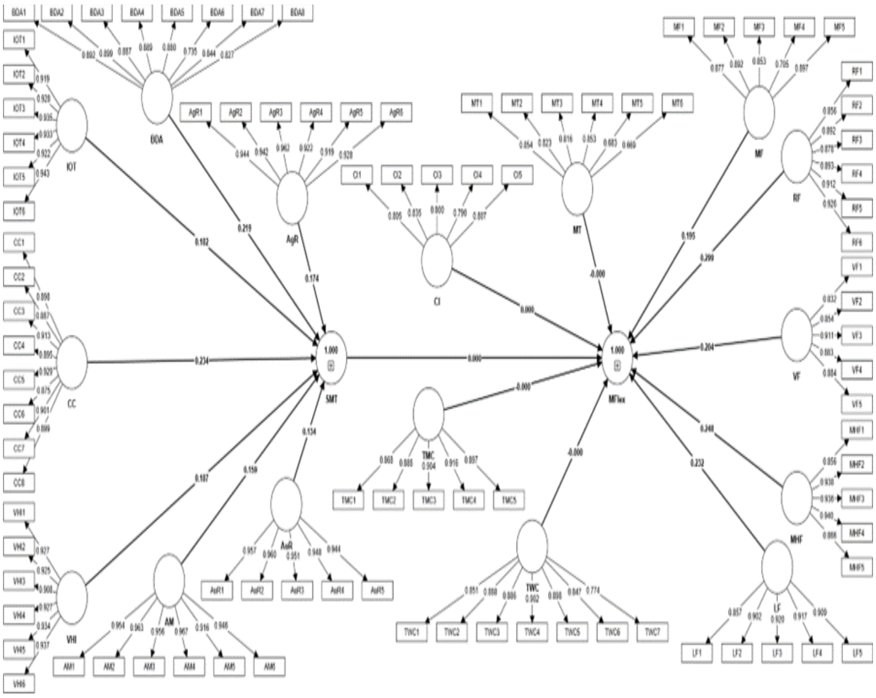
Content Validity

Content validity was done through face validity to assess the degree of accuracy and appropriateness of the construct. The face validity was done by asking people to review the measurements techniques known as the preliminary test. It involved 3 academicians, and 3 practitioners who were the specialists in the operation or supply chain management. By this way, the author will be alerted should there be any potential problems that may be caused by the questionnaire design. The feedback received from the participants were used to improve the content of the instrument.

Empirical Assessment of the Construct

Since this study employed the explanatory nature of the research, PLS-SEM was used in the study (Hair et al., 2017). To validate the measurement instrument empirically, the measurement model was examined to test the validity and reliability of the instruments. The data were analyzed by using structural equation modelling (SEM) with SmartPLS4.

Figure 1: Factor loading for each measurement.



All the factor loadings were greater than the threshold value of 0.5 (actual values range from 0.669 to 0.963). Therefore, it can be concluded that all the indicators' reliability test has been satisfied and none of the indicator need to be removed from the model. Equally important is the Cronbach's Alpha values for all the constructs range between 0.867 to 0.979 which above the 0.60 acceptable value (Hair et al., 2011). Similarly, the actual AVE values after using the SmartPLS4 software for all the constructs ranging between 0.619 and 0.907 which satisfied the threshold value of 0.50 (Hair et al., 2011). In conclusion factor loadings, CRs and AVEs indicated that the convergent validity has been met.

Apart from convergent validity, discriminant validity is another criterion needed for construct validity. Henseler et al. (2015) and Voorhees et al. (2016) have suggested to evaluate the discriminant validity using the Heterotrait-Monotrait ratio of correlations (HTMT) test. According to Henseler et al. (2015) and Voorhees et al. (2016), to evaluate the discriminant validity is by using the Heterotrait-Monotrait ratio of correlations (HTMT) test. Kline (2011) has suggested 0.85 as the cut-off value for the HTMT test. Based on the result, none of the value is above 0.85. Therefore, the convergent validity has been established based on the HTMT test.

Conclusion and recommendation

The objective of this paper is to develop and validate the measurement instrument for the contributing factors that can enhance manufacturing flexibility implementation in mass customization production system in Malaysia. This was accomplished through review on literature that study about manufacturing flexibility. Subsequently, a systematic validation process involving the content validity and construct validity of the measurement have been done. Result of the study shows that the model has met the requirements for the content validity as well as construct validity. The respondents were among the middle to top management staffs who are very familiar with the production process. The assessment indicates that all the activities measure their underlying construct (first-order construct) which signified its contribution. Similarly, all the smart manufacturing technology and manufacturing flexibility measure their second-order construct. The result is comparable with the past study by Tsai & Yeh (2019) and Amoako-Gyampah et al. (2018) that found similar result in their studies.

Studies among 145 discrete manufacturing process companies in Malaysia also found the importance of smart manufacturing technology, organization, and environmental factors towards manufacturing flexibility implementation.

The extensive review on the literature and comprehensive assessment by the academic and practitioners' experts established content validity for the measurement constructs. Similarly, the use of large number of samples would empirically validate the measurement constructs. Based on this study there were empirical evidence that content validity, construct validity and criterion related validity of the measurement have been established. Therefore, this study could provide a valuable tool for researchers to gain deeper understanding about how to implement manufacturing flexibility effectively. Future researchers could use the measurement construct in this research to examine the causal model of manufacturing flexibility implementation.

This research study was conducted during the Covid-19 pandemic, as businesses were struggling to recover from the movement control order (MCO). Many manufacturing firms were asked to shut down their operations several times in a year due to the MCO. As a result, the response rate for this study was only 15.5%.

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