Parte I

Uso de PLS SEM

Capítulo 1

Factors to Evaluate Advanced Manufacturing Technology

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Abstract

Companies are looking for strategies to improve their products and processes; thus, they resort to the adoption of Advanced Manufacturing Technology (AMT), which represents a source of competitive advantage. The evaluation of alternatives is an essential phase and an important problem because there is no generalized agreement in practice or theory on the factors of analysis or how to approach them. Therefore, the objective of this chapter is to determine these factors, using Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA) and Structural equation modeling (SEM). After conducting a literature review and subjecting the data to nomological and empirical validation processes involving experts, the techniques revealed 21 adoption indicators grouped into 6 key driver factors: strategic, technical, economic, human, administrative, management support, and manufacturing.

Introduction

Advanced Manufacturing Technology (AMT) is essential for achieving manufacturing companies' strategic goals by enhancing product development, planning, processes, and control. It strategically optimizes business activities and serves as a model to adapt to the operating environment. AMT, as both an approach and philosophy, efficiently integrates design and manufacturing functions through computer systems and data management (Azemi et al., 2019; Bedworth et al., 1991; Wilhelm & Parsaei, 1991; Yu et al., 2015). The widespread adoption of AMT brings both quantitative and qualitative benefits across various production stages, including product design, manufacturing planning, material handling, real-time tracking, and product quality improvement (Berman et al., 2009; Cotton & Schinski 1999; Marri et al., 2000). However, organizational structural changes are often necessary for successful adoption because of technological complexity, as noted by Lucianetti et al. (2018) and Saberi et al. (2010). Although extensive literature exists in AMT implementation processes, effectiveness, and associated risks, much of it remains anecdotal and controversial. Although it constitutes valuable empirical evidence, it is not conclusive.

Therefore, it is crucial to conduct cutting-edge research on the factors influencing its effectiveness.

AMT evaluation is crucial during the planning phase. Assessment must be correct, objective and comprehensive to select the best option (Lakymenko, Alfned & Thomassen, 2016). It should consider diverse interests, including long-term effects, competitiveness, equipment reliability, user-friendliness, and other variables (lo Storto, 2018). Effective planning requires analyzing various qualitative and quantitative factors, understanding their interplay within and outside the company, and assessing the industrial environment (Al-Ahmari, 2008). This ensures a confident decision regarding the technology that best fosters business development and competitiveness. The subsequent paragraphs discuss some models for evaluating these factors and their associated challenges (Ocampo, Hernández-Matías & Vizán, 2017).

In industry, companies prefer quick and precise evaluation of AMT using simple quantitative models, such as net present value and cost-benefit. However, these models are inadequate for assessing alternatives because they focus solely on short-term quantitative variables and rely on numerous assumptions to handle uncertainty. They often overlook qualitative variables that are challenging to quantify or aggregate. Critics argue that these models provide limited information and fail to address the complex nature of technology assessment. Other studies, such as those by Hayes and Wheelwright (1984), Kaplan and Atkinson (1989), Sherman et al. (1993), and Wang et al. (2011), highlight the limitations of these models in analyzing technology's impact on the entire manufacturing system. Additionally, lo Storto (2018) noted that these models are criticized for assuming that all factors are equally important. Meanwhile, models that consider both qualitative and quantitative factors are relatively efficient and face various challenges in application.

The literature reports on qualitative and quantitative evaluation factors for AMT/MIC analysis. Some authors suggest up to 45 factors (Boelzing & Shulz ,1989; Liberatone et al., 1992; Ocampo & Hernandez-Matías 2017; Wang & Hong 2011), while Hon (2005) mentions a staggering 442 factors due to evolving manufacturing systems. This complexity arises from a lack of widely accepted determining factors, which can lead to content-related analysis challenges. Similarly, Chuu (2009) noted that measuring qualitative criteria and attributes lacks consistency because they often lack an objective scale or uniform units, raising doubts about aggregation, whether additive or multiplicative. Moreover, assessment models tend to be imperfect representations of problems because of the subjective and arbitrary nature of factor selection (Chuu, 2009; Gervásio & Simoes, 2012). Given these considerations, the following sections outline the methodology for identifying constructs and factors for evaluating advanced manufacturing technology.

Methodology

Factor identification

The literature review covered documents published between 1990 and 2020. We began with a general search using Google Academic to identify relevant databases for Advanced Manufacturing Technologies (AMT) and Computer Integrated Manufacturing (CIM). We used keywords like "Justification Methods for AMT or CIM" and "Strategy Manufacturing." The selected studies were published in English after 1990 to trace the evolution of technology and critical factors in manufacturing. This process yielded 102 articles that were analyzed for context, problem, objective, application, and results. We then applied a Systematic Review of Literature (SRL) with Colin's criteria (2007), resulting in the final selection of 23 articles. These articles mentioned various factors related to advanced manufacturing technology. In summary, the review identified 51 decision factors and 95 manifest variables from 1990 to 2020.

Method

We used a survey method to group latent variables and assess their alignment with literature findings. Expert judgment, following Capella-Peris et al. (2016) procedure and Kendall's W index, validated these factors. The questionnaire had two sections: one for personal information and the other for study variables. A 5-point Likert scale was used to indicate respondents' perceptions of each factor's intensity. The sample includes middle and senior managers in advanced manufacturing. We empirically confirmed variable reliability using Cronbach's alpha, considering removal for increased reliability. Sample size was 220 according to Hair et al. (2014) guidelines. Factor identification involved exploratory and confirmatory factor analyses (EFA and CFA) using structural equation modeling on randomly split subgroups.

Selection of criteria and factors

SRL of the 102 selected articles yielded 23 articles, identifying 51 factors categorized into seven constructs: Strategic (10 factors) (Chuu, 2009), Economic (5 factors) (Olfati et al., 2020), Technical (6 factors) (Mkrkdtth & Surksh, 1986), Human (7 factors) (Waldeck & Leffakis, 2007), Manufacturing functions (19 factors) (Hitomi, 1990), Administrative functions (2 factors) (Saberi et al., 2010), and Sustainability (2 factors) (Niaki et al., 2019). The factors within each construct vary. For example, the Strategic construct considers the impact of AMT/MIC on competitiveness, market performance, strategic objectives, and innovation strategy (Terziovski, 2010). Table 1 summarizes the variables of each construct.

Table 1
Factors by construct and authors

Construct/variables Qty	Decision Factor	Authors
	Strategic aspects	Bhatt (2016)
	Structural changes in the company	Bhatt (2016)
	Commercial	Evans et al. (2012)
	Competitiveness	Falkner & Benhajla (1990)
	Growth or expansion	Falkner & Benhajla (1990)
Strategic/10	Establishing short-term objectives	Bhatt (2016)
	Strategic	Cescon (2010); Evans et al., (2012)
	Strategic impact and competitive position	Cescon (2010); Bülbül et al., (2013); Mohanty & Venkatraman (1993);
	Innovation	Venkatraman(1993); Iakymenko et al., (2016); Ocampo et al., (2017)
	Improved marketing performance	Ghobakhloo & Hong (2014)

Construct/variables Qty	Decision Factor	Authors
	Selection of technology suppliers	Bhatt (2016)
	Technicians	Evans et al., (2012)
	Technologic transfer	Bhatt (2016)
Technical/6	Connectivity and communication arrangements for assimilation	Bhatt (2016)
	ATM Integration	Bhatt (2016)
	Information capabilities	Al-Ahmari (2008); Madu & Georgantzas (1991)
	Net present value	Liberatore et al., (1992)
	Monetary	Falkner & Benhajla (1990)
Economic/5	Improved financial performance and financing	Evans et al., (2012); Ghobakhloo & Hong (2014);
	Economics	Cescon (2010); Io Storto (2018)

Construct/variables Qty	Decision Factor	Authors
Human/7	Human factor	Bhatt (2016)
	Rejection by workers	Aravindan and Punniyamoorth (2002)
	Reduction in direct labor	Madu and Georgantzas (1991)
	Need to train qualified personnel to handle ATM or MIC.	Bhatt (2016)
	Impact of human resources	Ordoobadi (2013)
	Social aspect	Bhatt (2016)
	Learning	Aravindan and Punniyamoorth (2002); Mohanty & Venkatraman (1993)

Construct/variables Qty	Decision Factor	Authors
	Customer service	Liberatore et al. (1992); Ocampo et al. (2017)
	Service improvement	Bülbül et al. (2013); Ocampo et al. (2017)
	Quality	Boelzing and Schulz (1989); Bülbül et al., (2013); Cescon (2010); Göleç & Taşkın (2007); Iakymenko et al., (2016); Liberatore et al., (1992); Ordoobadi (2013); Wang et al. (2011)
	Increased capacity	Aravindan and Punniyamoorth (2002); Boelzing & Schulz (1989); Cescon (2010)
	Reliability	Göleç & Taşkın (2007); Madu & Georgantzas (1991); Ordoobadi (2013)
Manufacturing/19	Costs	Al-Ahmari (2008); Bülbül et al. (2013); Iakymenko et al. (2016); Mohanty & Madu & Georgantzas (1991); Göleç & Taşkın (2007); Ocampo et al. (2016); Ordoobadi (2013); Venkatraman (1993); Wang et al. (2011)
	Development of new metrics to assess ATM impact	Bhatt (2016)
	Design	Al-Ahmari (2008)
	Effective time	Aravindan and Punniyamoorth (2002)
	Overall equipment effectiveness	Nath and Sarkar (2017)
	Flexibility	Bai and Sarkis (2017); Bülbül et al. (2013); Io Storto (2018); Ordoobadi (2013)

Construct/variables Qty	Decision Factor	Authors
Manufacturing/19	Inventory	Cescon (2010); Falkner & Benhajla (1990)
	Personalization	Iakymenko et al. (2016)
	ATM or MIC implementation practices	Bhatt (2016)
	Process	Al-Ahmari (2008); Io Storto (2018)
	Reduction of waiting times	Cescon (2010)
	Repeatability	Mohanty and Venkatraman (1993)
	Security	Cescon (2010)
Administrative functions & management support/2	Non-technical	Evans et al. (2012)
	Senior management support	Bhatt (2016)
Sustainability/2	Environmental risk	Nath and Sarkar (2017)
	Sustainability	Bhatt (2016); Iakymenko et al., (2016)

The technical construct highlights technology selection, transfer, integration, and technician roles. Economic criteria include net present values, monetary indicators, financial ratios, and perceived investment risk. The Human construct involves customer perceptions of quality, service, and satisfaction, worker perceptions, training requirements, and learning curves. The manufacturing criteria encompass functions such as design, production, logistics, inventory, research and development, material-handling, and maintenance. Administrative and sustainability criteria focus on non-technical aspects and environmental considerations, respectively. Sustainability criteria encompass various aspects like waste, hazardous substances, and environmental flexibility (Nath & Sarkar 2017). Furthermore, Bai and

Sarkis (2017) suggested that AMT evaluations should include sustainability considerations, which involve factors like green flexibility, energy flexibility, the ability to handle eco-friendly or biodegradable products, and pollution control flexibility.

As observed, there is no clear consensus on the decision factors, both quantitative and qualitative, leading to controversies about what should be analyzed. This highlights the significance of studying this issue due to the lack of a universally accepted theory and robust explanatory model for evaluating AMT.

Measurement model evaluation

Three experts evaluated the relevance of the 95 criteria in a concordance test, eliminating 49 criteria with a standard deviation greater than 1. Kendall's W parameter was calculated, yielding a result of 0.563 with a p-value of 0.002, indicating expert agreement. An additional 18 criteria were removed because they were deemed irrelevant. Reliability was assessed using Cronbach's alpha coefficient (CA), targeting a range between 0.60 and 0.70, following Huang et al. (2013). The sustainability construct, with only one variable, was excluded. After removing 7 variables, the overall Cronbach's coefficient was 0.895. Table 2 summarizes the constructs and variables, resulting in the final selection of 21 factors.

Table 2
Summary of Constructs, Criteria, and Variables

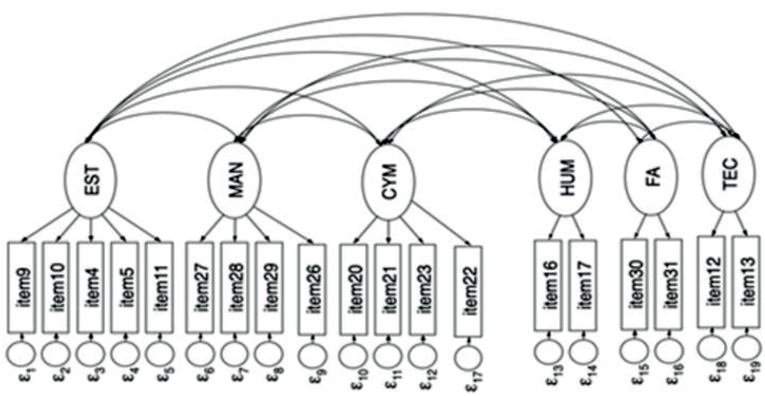
Construct	Variables
Strategic	Competitiveness, Growth, or Expansion, Strategic, Impact, and Competitive Position, Innovation, and Improvement in Marketing Performance
Technical	Selection of technology suppliers
Economics	Net Present Value and Monetary
Human	Reduction of the direct labor force and its social aspects
Manufacturing	Service improvement, Quality, Capacity enhancement, Reliability, Cost, Development of new metrics to assess the impact of AMT, overall team effectiveness, Flexibility and Process.
Administrative functions and management support	Non-technical aspects

To apply Exploratory Factor Analysis (EFA), sample adequacy must be assessed using criteria like sample size, Bartlett's sphericity test (p-value < 0.05), and Kaiser-Meyer-Olkin index (KMO > 0.80), as suggested by Hair et al. (2014) and Lloret-Segura et al., (2014). In this study, the sample size was 135, the Bartlett's test p-value was 0.000, and the KMO was 0.884, meeting these criteria. Therefore, EFA is suitable for determining factors/ components for Confirmatory Factor Analysis (CFA).

Principal component extraction with Varimax rotation and Kaiser normalization was performed to achieve at least 60% explained variance, as recommended by Hair et al. (2014). In this study, the total explained variance is 63.45%, and six factors are identified based on eigenvalues exceeding 1. These factors were identified as follows: the Strategic component (EST) consists of five criteria, Manufacturing (MAN) consists of four criteria. There are four criteria in the third component named Quality and Improvement (CYM). The Fourth Component, Technical (TEC), relates to supplier selection in two variables. The fifth component, Human (HUM), comprises two variables. The sixth component, Administrative Factors (FA), includes two variables concerning non-technical aspects, such as administrative changes and company operations. Thus, the theoretical model comprises six latent factors with 19 observable variables.

Confirmatory Factor Analysis (CFA) establishes causal relationships between model variables and measures psychometric properties (Byrne, 2006; Medrano & Muñoz-Navarro, 2017). This study defines a model with 6 specified factors and 15 relationships as Latent Exogenous variables (Figure 1). With 137 degrees of freedom, the model was over-identified, allowing estimation and contrast.

Figure 1
Measurement model of the factors evaluating AMT



CFA assumes multivariate normality; however, in this study, the Mardia mSkewness (117.054, $p>0.05$) Mardia mKurtosis (503.412, $p>0.05$) and Henze-Zirkler (1.954, $p>0.05$) tests rejected this assumption. Consequently, the ML method with Satorra-Bentler adjustment was applied (Ullman & Bentler, 2013). Goodness-of-fit indices, including CMIN/gl (1.347), RMR (0.051), CFI (0.945), and TLI (0.931), met or exceeded the recommended values, indicating a good model fit. The RMSEA (0.051) was below the desired threshold (0.07), signifying no statistically significant difference between the proposed and theoretical models (Escobedo et al., 2016; Hair et al., 2014; Hooper et al., 2008), eliminating the need for model re-specification (Ullman & Bentler, 2013).

Additionally, convergent validity was assessed using the Average Variance Extracted (AVE). The AVE values are displayed in bold on the diagonal of the matrix in Table 3. All of them surpass the minimum recommended value of 0.05 proposed by Huang et al., (2013). Consequently, the model demonstrates convergent validity, signifying that observable variables linked to latent factors capture more variance than errors (Hair et al., 2014). Discriminant validity was assessed using the Fornell-Larcker criterion (Escobedo et al., 2016), which compares the square root of the AVE to inter-construct correlations. All variables met this criterion because the AVE values surpassed the square correlations with other latent variables (Table 3).

Table 3

Discriminant validity

Factor	EST	MAN	CYM	HUM	FA	TEC
EST	0.522					
MAN	0.380	0.611				
CYM	0.321	0.503	0.550			
HUM	0.250	0.352	0.283	0.507		
FA	0.159	0.275	0.205	0.159	0.621	
TEC	0.318	0.288	0.300	0.287	0.159	0.585

The results of the structural model applied in this research reveal that the effectiveness of advanced manufacturing technology evaluation is strongly related to six key constructs: strategic components, manufacturing, quality and improvement, human resources, administrative factors, and technical aspects. These findings suggest that to effectively assess advanced manufacturing technology, it is essential to consider a combination of elements that not only involve technical and operational aspects but also strategic and managerial factors, reinforcing the need for a holistic evaluation approach, in line with the studies of Al-Ahmari,2008; Evans et al., 2012 and Luacenetti et al., 2018. The model underscores the importance of integrating qualitative dimensions, such as human resources and administrative factors, into an evaluative framework that often prioritizes quantitative aspects. In this regard, it is proposed to expand these qualitative aspects as additional criteria in quantitative studies, such as those conducted by Gervasio & Simoes (2012), Chuu (2009), or Bhatt (2016). This approach considers aspects that are not traditionally accounted for by multi-criteria methods such as AHP or Fuzzy Logic.

The theoretical framework highlights that there is no consensus in the existing literature on which factors are most important for evaluating advanced manufacturing technology. Most models tend to focus solely on either quantitative or qualitative variables, leaving a gap in the comprehensive understanding of the phenomenon. The findings of this study suggest a need for further research that integrates both perspectives, particularly through methodologies that quantify the impact of intangible variables, such as human resources or administrative factors, in a numerical way. However, this contrasts with the position of Olfati, Yuan & Nasseri (2020), who argues that the evaluation of advanced technology should be based solely on purely quantitative tools, disregarding non-directly observable aspects that, although not immediately visible, can still be statistically quantified. While Olfati et al., perspective emphasizes precision and objectivity, it may overlook critical factors, such as organizational culture or employee engagement, which can significantly influence the effectiveness of technology adoption. Incorporating these qualitative dimensions could provide a more comprehensive understanding of the variables at play, leading to more robust and informed decision-making processes. Therefore, this would allow for a more accurate capture of the impact of these constructs on the effectiveness of technological evaluation.

Conclusion

In this chapter, we present a new factor structure for evaluating advanced manufacturing technology. This structure includes the following six critical factors and their corresponding measurement scales:

I. Strategic: evaluates whether a company employs new product development, market segmentation, and expansion strategies to meet rapid innovation demands.

II. Manufacturing: assesses the organization's ability to enhance operational efficiency, infrastructure, and processes to develop manufacturing competencies for economies of scale and customization.
III. Humans: measures the impact of automation on reducing direct labor costs, transforming manual tasks into technology-based management, and improving worker motivation and commitment.
IV. Quality and Improvement represents a latent variable for future investigations, examining the effectiveness of AMT adoption.
V. Administrative: measure improvements in daily administrative procedures and operations, adapting them to advanced technology contexts.
VI. Technical: evaluates the supplier selection process for high-tech equipment and integrators capable of customizing solutions to align with organizational competitive strategies.

Furthermore, the validation process revealed that advanced manufacturing technologies were most adopted in the automotive sector (55.56%), followed by equipment design, manufacturing, and integration companies (15.56%), manufacturing firms (10.37%), electronics companies (8.15%), and the medical industry (6.67%). These findings should be interpreted cautiously, given the sample's focus on the Maquiladora export industry in Ciudad Juarez. Nevertheless, it is evident that 70% of the studied companies adopting AMT belong to the automotive industry, which demands flexible equipment and processes for economies of scale and customization. Similarly, equipment design and manufacturing companies strive to meet market demands by developing cutting-edge products. This underscores the importance of having an instrument that not only collects vital management information but also assesses the alignment of adoption of AMT with predefined strategic goals.

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