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Modelling critical success factors for the implementation of Industry 4.0 in Indian manufacturing MSMEs

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Abstract. This research is based on the recent endeavors of the manufacturers to achieve improvements in supply chain resiliency by implementing Industry 4.0 standards. The large enterprises, in today's scenario, are pursuing their supplier organizations to incorporate information and communication technology (ICT) based advancements to their production systems. But successful implementation of such technologies in the resource deficient supplier organizations depends on several factors that need due consideration of the decision makers. In this paper, we have identified 14 such critical success factors from extant literature for implementation of technologies conforming to Industry 4.0. Further, through an empirical investigation comprising of 222 micro, small and medium enterprises (MSMEs) from the automotive manufacturing sector in India, we have made use of exploratory factor analysis and structural equation modelling to identify the hidden constructs and examine the influencing relationships between them.

Keywords: Industry 4.0, MSMEs, supply chain, information sharing, structural equation modelling.

1. Introduction

The manufacturing industry across the globe are going through the Industry 4.0 led transformations. An essential requirement for the large enterprises (LEs) in the manufacturing industry is to improve their supply chain resilience against the propensity of efficiency [1], particularly in the face of disruptions of different kinds. For the LEs to achieve higher level of resilience, digitalization by including advanced technologies into the production processes is believed to be a key enabler [2]. Thus, to attain Industry 4.0 standards, manufacturers are keen to integrate advanced digital technologies such as intelligent robotics, artificial intelligence (AI), Internet of Things (IoT), Cyber-physical Systems (CPS), and Cloud manufacturing [3-4] into their manufacturing supply chains, which include their supplier organizations, mainly categorized as Micro, Small and Medium Enterprises (MSMEs). One key advantage of these technologies is the attainment of enhanced capability of sharing information. The importance of information sharing for attaining resilience in supply chain was adequately discussed in the literature [5-6].

The transition of the existing manufacturing scenario to a complete digital scenario of Industry 4.0 involves a number of challenges related to the formulation of new strategies of implementation, modification of the physical infrastructure, up-gradation of the manufacturing technologies, bringing out improvements in the organizational practices, and to the formulation of new coordination and contracting policies. This transition requires the manufacturing organizations to initiate a number of projects for adoption of different enabling technologies [7]. The adoption of advanced technologies would be challenging considering technical issues, quality and availability of infrastructure, data handling capability, skill gaps, etc. [8]. Typically, in the automotive sector, LEs are having ample resources to invest in advanced-technology adoption endeavors such as R&D and technology acquisition. In contrast, their supplier enterprises, falling in the category of MSMEs, are known for low technology levels and scarce capital resources, implying that such endeavors are difficult for them to pursue [7-9]. Accordingly, external interventions are necessary to assist them to succeed in upgrading to Industry 4.0 [10]. Nevertheless, the technology implementation initiatives in the inbound supply chains of LEs depend on several factors and at the same time such implementation is expected to impact the MSMEs in several dimensions. A proper understanding of these factors and impacts would be helpful to the decision makers including business leaders, government agencies, investors and training providers [1].

An accepted definition of critical success factors (CSFs) describes them as the things that must go well to ensure success [11]. Adequate understanding of CSFs helps in reducing complexity and enabling the decision makers to concentrate on most important CSFs while making decisions at various levels of the decision-making process [7, 12-13]. In this paper, we investigate the CSFs for implementation of Industry 4.0 technologies from a viewpoint of information sharing. The research objectives lie in the identification of the hidden constructs from these factors and then analyzing the influencing relations between them.

The rest of the paper is organized as follows. Section 2 reviews the related literature and presents the identified CSFs. Section 3 describes the method used for survey and initial analysis of the responses. Section 4 gives the details of the formulation of the hypotheses and structural equation modelling. Section 5 discusses the findings and Section 6 concludes the paper.

2. Related literature

The literature in the manufacturing domain are found to include several recent publications related to the integration of advancements in information and communication technologies (ICT) into production systems. The transition to Industry 4.0 is possible for the manufacturing enterprises with the inclusion of advanced digital technologies such as intelligent robotics, Cloud manufacturing, artificial intelligence (AI), Internet of Things (IoT), and Cyber-physical Systems (CPS) into their production systems [14-15]. Such transition is believed to be capable of transforming the entire value creation process and hence many countries have taken initiatives in developing ecosystems supporting this technological revolution [10, 16]. Many of the articles published are related

to the CSF analysis for adoption of different technologies such as ERP, Cloud computing, Big Data, RFID, 3D printing, and Augmented Reality [8, 17-19]. While the concept of Industry 4.0 encompasses all of these technologies, articles addressing the CSFs in the context of their inclusive implementation are few [20-22], more so in the context of MSMEs in India.

Since the response of manufacturing industries towards the ongoing technology revolution is influenced by several factors unique for each nation, such as the available ICT infrastructure and the economic and political scenarios [23-24], we find the requirement of a study on the CSFs for implementation of Industry 4.0 technologies in the Indian manufacturing MSMEs. Accordingly, we explored the pertinent literature to identify 14 CSFs and ascertained their relevance by discussion with 5 experts from academia and 5 experts from industry. The CSFs identified are listed in Table 1.

Table 1: CSFs for Implementation of Industry 4.0 technologies

CSF No.	Description of the Critical Success Factor
CSF 1	Management commitment
CSF 2	Adequate financial support
CSF 3	Cross functional team formation
CSF 4	Efficient information management system (ERP, MES, PLM etc.)
CSF 5	High performance computing
CSF 6	Automated electronic data capture mechanism
CSF 7	Integration of wearable and mobile devices to cloud
CSF 8	Cyber security measures
CSF 9	Collaboration for information sharing
CSF 10	Consistent network connectivity
CSF 11	Semantic technologies
CSF 12	Collaboration platforms availability
CSF 13	Decentralization of decision making
CSF 14	Traceability system implementation

3. Materials and Method

A questionnaire-based survey was used to capture the perceptions of the MSMEs in the automotive sector of India on the enabling power of the CSFs (listed in Table 1) for advanced technology implementation, primarily focusing on information sharing on a 7-point Likert scale, where “1” means “very low” and “7” means “very high” enabling power. The questionnaire was administered to 280 manufactures from five major automotive manufacturing hubs in India located in and around Jamshedpur in the east, Chennai in the south, Pune in the west, Delhi in the north and Sanand in the north-west of India and obtained inputs from 222 enterprises. This accounted for a response rate of 79%. For any clarification on the questionnaire, the researcher was available either

in person or on the telephone, which ensured the removal of ambiguity. All the 222 responses were complete and hence were considered fit for further analysis.

The survey responses were subjected to exploratory factor analysis (EFA) to reduce the 14 CSFs into a smaller number of highly inter-correlated sets of hidden constructs using SPSS 22.0. The data collected for this study met the requirements prescribed by Hair et al. [25], with case-to-variable ratio more than 5:1, KMO 0.780 (greater than 0.5), p-value less than 0.05 and the EFA-yielded-constructs together explaining 77.54% of the variance. The Cronbach's alpha values for all the four identified components were found to be more than the acceptable norm of 0.6. The extracted constructs and their associated variables are shown in Table 2.

Table 2: Hidden constructs from Exploratory Factor Analysis

Components	Variables	Factor loadings	Cronbach's alpha
F1: Management initiatives for adoption of Industry 4.0 technologies	Management commitment (CSF 1)	.919	.862
	Adequate financial support (CSF 2)	.825	
	Decentralization of decision making (CSF 13)	.816	
	Cross functional team formation (CSF 3)	.802	
F2: Advanced network and information management systems	Efficient information management system (ERP, MES, PLM, etc.) (CSF 4)	.926	.919
	Cyber security measures (CSF 8)	.910	
	Consistent network connectivity (CSF 10)	.882	
	Traceability system implementation (CSF 14)	.829	
F3: Advanced information acquisition and processing technologies	High performance computing (CSF 5)	.890	.893
	Automated electronic data capture mechanism (CSF 6)	.867	
	Semantic technologies (CSF 11)	.841	
	Integration of wearable and mobile devices to cloud (CSF 7)	.822	
F4: Collaboration initiatives for information sharing	Collaboration platforms availability (CSF 12)	.916	.834
	Collaborations for information sharing (CSF 9)	.808	

4. Hypothesis development and structural equation modelling

4.1 Hypotheses development

On the basis of the opinions gleaned through the questionnaire survey and available literature (25-29), the following seven hypotheses are formulated:

H1: Management initiatives for adoption of Industry 4.0 technologies (F1) positively influence the availability of advanced network and information management systems (F2)

H2: Management initiatives for adoption of Industry 4.0 technologies (F1) positively influence collaboration initiatives for information sharing (F4)

H3: Advanced information acquisition and processing technologies (F3) positively influence availability of advanced network and information management systems (F2)

H4: Advanced information acquisition and processing technologies (F3) positively influence collaboration initiatives for information sharing (F4)

H5: Availability of advanced network and information management systems (F2) positively influence the Implementation of Industry 4.0 (II4)

H6: Advanced information acquisition and processing technologies (F3) positively influence the Implementation of Industry 4.0 (II4)

H7: Collaboration initiatives for information sharing (F4) positively influence the Implementation of Industry 4.0 (II4)

4.2 Structural Equation Modelling

We used structural equation modeling (SEM) using AMOS software package to test the validity of the hypotheses developed. The technique used was maximum likelihood estimation (MLE). In the path diagram produced using AMOS (see Figure 1), the CSFs, extracted constructs and error terms are shown as rectangular boxes, ellipse and circles respectively. While arrows between a pair of constructs represents the hypothesized relations, numbers beside them are the corresponding standardized direct effects. To bring in clarity, Figure 1 shows the standardized estimates for constructs and CSFs only. The quality of the model was evaluated using several goodness of fit indices usually recommended. The values obtained are chi-square/degrees of freedom 3.515, root mean square error of approximation (RMSEA) 0.107, comparative fit index (CFI) 0.903 and Tucker-Lewis index (TLI) 0.878. These indices are found to be in the acceptable range suggesting that the model fits the data well.

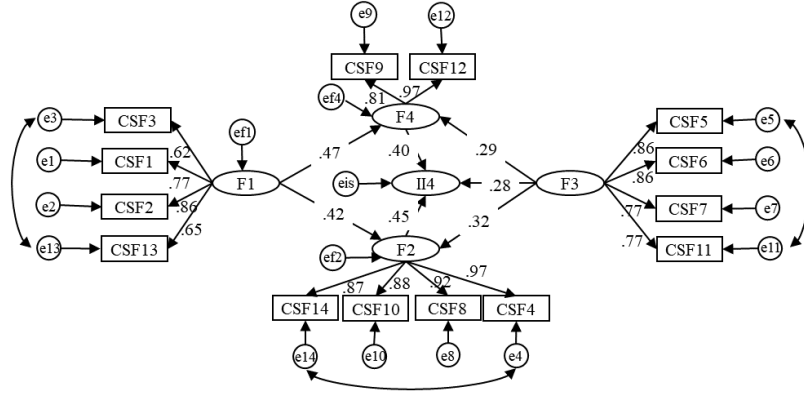


Figure 1: Estimates for the constructs in SEM using AMOS

5. Results and discussion

Figure 1 shows that all the hypotheses are supported by our survey responses. Figure 2 shows a conceptual model derived out of the structural equation model:

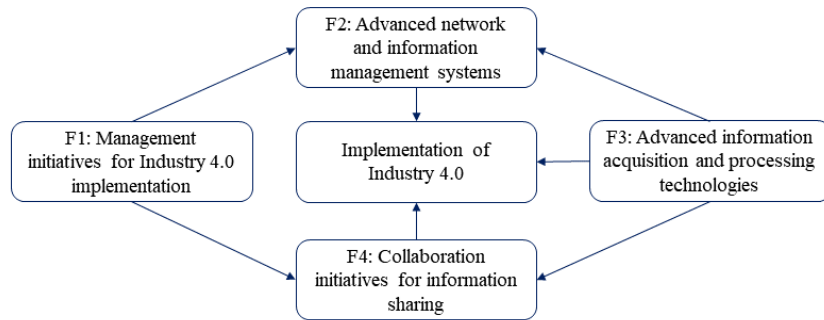


Figure 2: Conceptual model derived out of the structural equation model

The following broad inferences could be drawn from the results of this analysis:

- 1) The role of the management for technology upgradation of MSMEs is indispensable. The role of the management would be that of a resource provider as well as that of a collaboration facilitator for the partner organizations. The management needs to be proactive in establishing collaborations for information exchange, developing standard norms and capabilities.
- 2) Information collaboration involving advanced technologies demands an efficient network and information management system consisting of good IT infrastructure,

robust architecture, and well laid-out processes. Thus, the initiatives for implementing Industry 4.0 standards would improve the capability of data acquisition and the ability to improve the information management system of the MSMEs.

- 3) The technological upgradation will lead to the utilization of sensors and IoTs to generate big data in order to enhance a data centric production scenario. It would support the collaboration initiatives and information management by acquiring required data more effectively.
- 4) Adoption of Industry 4.0 technologies would also be beneficial for the organizations in their collaboration endeavors for effective exchange of information. For this, there is a need of a shared enterprise system comprising of information management systems for virtual integration of the collaborating enterprises.
- 5) The establishment of collaboration with other enterprises for sharing of information supported by advanced technology and information management systems would lead to the effective implementation of Industry 4.0.

The validity of the hypotheses also corroborates to the existing literature. To reap the benefits from the adoption of advanced technologies through information sharing, the MSMEs need to direct their efforts towards technology upgradation. This requires adequate patronage and active involvement of the top management [26-27], typically in planning and management of the technology upgradation process [27-28].

The technology upgradation process involves the inclusion of advanced technologies such as Internet of things, cloud computing, and robotics into the production systems. Analysis of Big data, traceability systems such as RFID and IoT, and the use of a shared information system would help managers to make more precise, practical, and reasonable decisions [29-30]. Hence, an effective system for information collaboration can emerge from technology upgradation of MSMEs.

Since most of the manufacturing MSMEs are part of bigger supply chains, the intention of implementing new standards and technologies of Industry 4.0 would be to improve the supply chain. In addition, due to the recent pandemic-led disruptions, supply chain resiliency is the key focus [1, 3]. While the role of information sharing in a resilient supply chain is prominent [5-6], an inter-organizational information system is the need of the hour [30].

6. Conclusion

In this research work, we have identified the critical success factors (CSFs) for the adoption of advanced technologies for Industry 4.0 implementation and derived the hidden constructs using EFA with the help of a questionnaire survey among Indian automotive manufacturing MSMEs. Subsequently, we have used structural equation modelling (SEM) to test hypotheses describing the influencing relations among the identified constructs.

The findings suggest the importance of management initiatives, advanced network and information management systems, advanced information acquisition and

processing technologies, and collaboration initiatives for information sharing for the successful implementation of Industry 4.0 in the Indian manufacturing MSMEs.

There are some limitations that may be addressed in forthcoming research. Even though a reasonable sample size is considered, it could have been larger, so that the validity is improved. Moreover, our respondents were from automotive industries only and hence the study can be extended to other sectors as well with necessary precautions.

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