IMPACT OF PRODUCT MODULARITY ON MASS CUSTOMIZATION CAPABILITY: AN EXPLORATORY STUDY OF CONTEXTUAL FACTORS

This study examines how the impact of product modularity on the mass customization capability is moderated by several contextual factors, such as the firms' information system capacity (ISC), teamwork (TW), multifunctional employees (MFE), and organizational structure (flat or hierarchical) (OSF). Data from 238 firms located in multiple countries across three different industry groups were analyzed to test the moderated regression models and the hypotheses. The results showed that the product modularity strongly impacts the mass customization capability (MCC). Compared to ISC, the social contextual variables, such as TW, MFE, and OSF, have stronger moderating effects on the impact of the product modularity on the mass customization capability. In addition, ISC helps MCC solely for firms with flat organizational structures. Overall, our study suggests that manufacturers who desire to become mass customizers should create flat, nimble organizations with employees who are trained in several different tasks and are adept at teamwork.

Keywords: Mass customization, product modularity, teamwork, organizational structure, information processing.

1. Introduction

Mass customization has become many companies' choice for competing in an environment characterized by heterogeneous customer demands, increasing investments in new product development, and shortened product life cycles.[1,2] Both researchers and practitioners are seeking the means to improve the mass customization capability (MCC) (e.g., Refs. 3-6), which can be defined as the ability to reliably offer a high volume of different product options to better meet customer demands without incurring substantial tradeoffs in cost, delivery, and quality.[2,7] Many researchers have proposed that product modularity is an important manufacturing practice for MCC (e.g., Refs. 1, 2, 4, and 8-14). However, in the current information age, the spillover effect of knowledge is very significant and the knowhow regarding the modular design of products diffuses very quickly among the competitors. Moreover, it is very common that the same suppliers serve different manufacturers in one industry, which increases the standardization of the parts and further promotes the diffusion of the modular design. Therefore, product modularity becomes a trend in the industry rather than a company's unique features. However, each manufacturer in the same industry utilizes different levels of MCC. These variances may be caused by the unique contextual factors of each manufacturer. Most of the extant literature emphasizes the role of modularity in developing the MCC, and minimal focus has been given to the context and systems in which the influence of product modularity is embedded.[2,15,16]

Mass customizers rely on a bundle of manufacturing practices to cost-efficiently deliver products or services in response to the needs of a particular customer.[17] Thus, the MCC increases the complexity of end products, raw materials and components, and routings, forcing manufacturers to adopt advanced, non-routine, and un-analyzable technologies that fundamentally change the nature of the firm.[18] The increasing task uncertainty may cause many management problems associated with integrating new manufacturing technologies.[19] To mitigate such an uncertainty, manufacturers must improve their information processing capabilities.[20] Furthermore, the social and human systems of the organizations must also be redesigned to match these complex environments and associated advanced technologies.[21-23]

As a new manufacturing paradigm, the successful implementation of mass customization requires manufacturers to integrate and coordinate new technology with humans and organizations. In this study, we performed an in-depth analysis of the impacts of the contextual factors, the product modularity, and the information system capacity in order to better understand how MCC can be successfully developed. The main research question was as follows: how can an organizational context be built to enhance the impact of the product modularity on MCC?

To achieve this objective, we relied on the information processing theory[20,24] and the socio-technical system theory[25,26] to identify the contextual factors. Basically, the former argues that the demands for information processing are determined by the nature of the task, and an organization can increase such capacity through certain information processing alternatives (IPAs). The latter proposes that the organizations are composed of both social and technical subsystems, and organizational designers should jointly optimize both subsystems.

This study contributes to the literature in several ways. First, we identified the contextual factors that enhance the impact of product modularity on MCC. Second, we investigated the development of MCC from a balanced perspective of the firm's socio-technical system instead of solely focusing on the technical aspects, which has been commonly done in previous mass customization studies (e.g., Refs. 7 and 27). Third, by combining the socio-technical system perspective and the information processing perspective, we investigated the effects of interaction between the social and technical components of the IPAs, including teamwork (TW), multifunctional employees (MFE), and the organizational structure (flat or hierarchical) (OSF), which are all considered very important in MCC development.[2]

2. Literature Review and Research Hypotheses

Figure 1 shows the theoretical model used in this study. The model depicts the direct impact of the product modularity on MCC, the moderating effects of the firm's information processing capacity, and the salient characteristics of its socio-technical system.

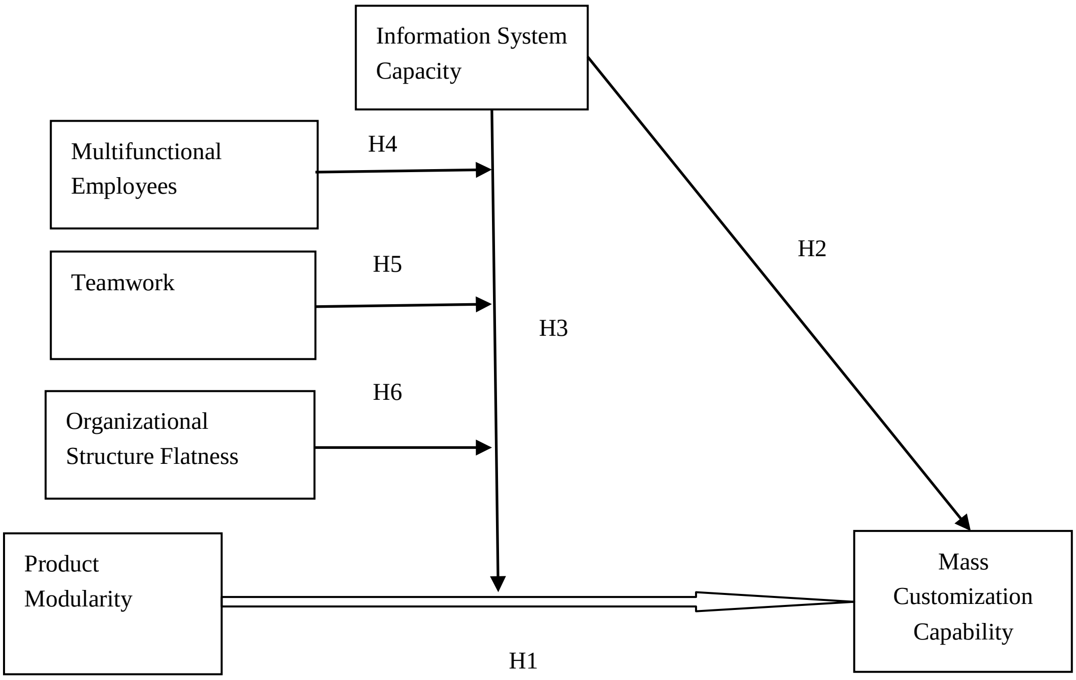

Figure 1. Research Framework and Hypotheses

2.1. Information processing theory and socio-technical systems

The basic proposition of the information processing theory is that the greater the uncertainty of a task, the greater the quantity of the information that must be processed during the execution of the task.[28] An organization is an open system that must process information; however, it has limited capacity to do so due to the restrictions put upon it by its resources and internal systems.[29] Managers must carefully and efficiently deploy resources and design systems to match the organization's information processing capability with the information processing requirements of its environment.[19]

Although the information processing theory has a long history, it recently began to appear in operations management research.[30] This theory has never been used in complexity management, information technology, maintenance management, project management, product development, high technology innovation, and the supply chain management literature (e.g., Refs. 31-34). Galbraith[24] proposed an information processing model in which he suggested that organizations could adopt four types of information processing alternatives: the creation of slack resources, the creation of self-contained tasks, the investment in vertical information systems, and the creation of lateral relations. Based on this model, Flynn & Flynn[30] empirically tested the role of these four alternatives in coping with the increased environmental complexity and found that practices related to self-contained tasks, lateral relations and certain environmental management strategies are effective in managing manufacturing uncertainty, whereas the investment in information systems does not have a significant effect. Bozarth et al.[34] extended this analysis to the supply chain environment and explored how the four alternatives affect the impact that supply chain complexity has on plant performance.

Certain researchers found that the investment in information systems is less effective without the support of social systems.[30,35,36] Bendoly & Swink[33] also suggested that behavioral issues should be considered in future information processing research. Socio-technical systems propose that the production process consists of two interdependent dimensions: the technical system and the social system.[21] The former consists of the equipment and operating methods used to transform materials into products, whereas the latter includes the work structures that relate people to the technology and to each other. The core concept of the socio-technical system theory is that the organization's social and technical subsystems should fit with each other and be treated as interdependent aspects of a whole system. The collection of information, technology, people, and structure form a socio-technical web inside the organization, which should be designed according to the frequency of product and process renewal and the degree of dynamism in the market.[22]

Originally, the socio-technical perspective was mainly used in discussing the principles of work design practices.[25,37] Currently, this perspective is widely viewed as a useful framework for assessing the system-wide implications of new manufacturing strategies, such as total quality management,[38] lean production,[39] cell manufacturing,[40] and mass customization.[2] For example, Hirschhorn et al.[41] argued that jointly optimizing the social and technical systems is very important for the success of mass customization. Liu et al.[2] empirically proved that several work-design practices, such as the feedback to the shop floor, autonomous maintenance, cellular-manufacturing, multifunctional employees, high standards for recruiting, task-related training, differentiated reward and incentive systems, employee-contribution willingness, and continuous improvement all positively contributed to MCC improvement. Extant studies provide empirical evidence that the information processing theory and socio-technical systems are useful perspectives for understanding MCC development. However, the impact of the mutual adaptation of these social and technical systems on MCC, which is imperative for the successful implementation of a new technology, must be explored.

2.2. The impact of product modularity on MCC

Product modularity refers to the decomposition of the complex end product into sub-modules that can be easily assembled together.[42] Products are separated into modular components that can then be configured into a wide range of end products.[43] Salvador[44] further explained that product modularity includes component combinability and component separability. By decomposing complex end products into simpler components, modularization isolates and separates component production.[45]

The literature views product modularity as one of the best means to achieve MCC.[4,8,10,11,44] Product modularity helps manufacturers to cope with in-line complexity due to ever increasing product variety and improves MCC by providing strategic flexibility in terms of greater product variety, higher flexibility, a faster speed to market, and lower costs for design, production, distribution and service.[46,47] According to Feitzinger & Lee,[10] product modularity benefits MCC in three ways: 1) maximizing the number of standard components to pursue economies of scale; 2) manufacturing different modules at the same time to shorten the total required lead time; and 3) diagnosing production problems and isolating potential quality problems. The more modular the product architecture, the easier it is for mass customization to occur.[2,11] Therefore, we propose the following hypothesis:

H1: Product modularity is positively related to MCC improvement.

2.3. The effect of information system capacity

Many researchers have proposed that the information system capacity is an important enabler for mass customization (e.g., Refs. 1, 3, 4, and 48). Mass customizers must address high product variety, which requires them to elicit information from individual customers and incorporate this information into the design and production processes.[8,14] Thus, manufacturers rely on the information system to provide information processing support to the management of product variety.[49] To process information quickly and efficiently, manufacturers must increase the capacity of existing channels or create new channels to address the information processing demands. Information technologies can support mass customization by facilitating information processing and exchange, collaboration, and the creation and sharing of knowledge.[50,51] Furthermore, the increased capacity of the information system helps an organization address increasingly complex information needs associated with MC, making it easier for decision-makers to address exceptions.[30,34] Therefore, we propose the following hypothesis:

H2: Information system capacity is positively related to MCC improvement.

Product modularity requires manufacturers to address unpredictable inter-module or inter-system interdependences,[47] which increases the effort (e.g., logistics, marketing, and retail) required to coordinate these components.[11] Thus, assembling and configuring modules into final products involves several information processing tasks, which means that the effectiveness of the product modularity design depends on a firm’s information processing capacity. According to the information processing theory, a firm’s information processing capacity can shorten the length of decisions, broaden the scope of the available database, formalize the information flow inside the organization, and facilitate group decision making.[20] Information technology can reduce errors in data collection and accelerate data movement.[47] Thus, the efficiency and effectiveness of the infrastructure to communicate and interact with customers and suppliers depends on a firm’s information system capacity. Subsequently, firms can quickly and efficiently translate a customer’s requirements into a modular design when suppliers’ capabilities are also considered. The information system also helps manufacturers define the product family through the collection and storage of customers’ choices and preferences and help firms satisfy customers through the optimal scope of the modular design, which greatly increases the effectiveness and efficiency of mass customization. Furthermore, the information system can translate the design characteristics into processing specifications more quickly and accurately, which facilitates the identification of the commonalities among the parts.

Therefore, we propose the following hypothesis:

H3: The impact of the product modularity on MCC is moderated (enhanced) by the capacity of an organization's information system.

2.4. The effect of multifunctional employees, teamwork, and organizational structure flatness

Higher information system capacities can increase the quantity of information, such as the number of messages transmitted and received by the manufacturers.[35] However, it is not sufficient for mass customizers to rely on information technology alone in order to cope with the information flow associated with product modularity.[47] Without the support of suitable social systems, employees can become overwhelmed by the huge quantity of information.[36] Furthermore, Ro et al.[12] concluded that the barriers to the realization of modularity gains are socio-technical in nature and cannot be easily discarded, overlooked, or overcome without the redesign of an organization's social and human system. Product modularity needs the coordination and cooperation of people in different departments, such as marketing, finance, R&D, manufacturing and distribution.[10]

Thus, to fully realize the potentials of product modularity and the information system capacity, manufacturers need to redesign their social and human systems. In this study, we focus on three social-oriented functions (multifunctional employees, teamwork, and structure flatness) that enhance the effectiveness of the product modularity and improve the information processing capability. These three functions are typical information processing alternatives.[24,30] Teamwork can create self-contained tasks and can facilitate lateral communications among employees. Multifunctional employees can be considered as a type of slack resource. Although employees have more skills than required by the tasks, the "slack" capabilities enable them to process information more efficiently and effectively.[34] A flat structure can create an internal environment that facilitates interactions and communications not only horizontally between employees in different functional departments but also vertically between leaders and subordinates; this creates lateral relations among functions.

A multifunctional employee implies that employees are trained to perform a variety of tasks. The ability of an employee to perform different tasks is very important for the manufacturer's capability to customize efficiently.[41] Mass customizers need to frequently adjust the designs and configurations of modules according to customers' requirements.[52] Thus, product modularity requires process flexibility and responsiveness, in which cross-trained employees play important roles.[53,54] When workers are trained to perform multiple jobs, manufacturers can easily reorganize the process and deploy those workers wherever they are required. Moreover, previous training can improve employees' understanding of new jobs and reduce the quantity of information to be processed. Thus, manufacturers can improve their information processing capability by using multifunctional employees who can absorb the impact of uncertainty by increasing the availability of human resources.[34] Furthermore, manufacturers can reduce the uncertainty caused by the division of labor and provide flexible human resources that can be easily reorganized to produce different modules according to customers' demands and design changes. Therefore, the information system and multifunctional employees are complementary elements that can work together to support product modularity. The impact of product modularity on the MC capability is enhanced when the manufacturers simultaneously improve the information system capacity and use multifunctional employees. Therefore, we propose the following hypothesis:

H4: The impact of product modularity on MCC is enhanced by the interaction between multifunctional employees and the information system capacity.

Teamwork refers to the formation of teams in the manufacturing process when there are problems. As suggested by Galbraith,[24] if the tasks affect several different parties, creating a permanent or temporary team is a good choice. Gathering people with various backgrounds facilitates mutual understanding and communications among employees. Furthermore, different functions, such as accounting, marketing, engineering, and manufacturing are all important for improving the MC capability.[5,10] Employees representing different functions may have different priorities during the design and production processes, and teamwork enables these employees to process related information together and collaborate on important decisions. In such work groups, lateral communication is predominant, and members are viewed as flexible human and knowledge sources. The use of lateral communication improves the decision quality by presenting information that is relevant to problem solving.[34] This can assist manufacturers in their coordination and optimization of module production and in cooperatively solving conflicts. Consequently, through creating lateral channels for communication, coordinating decisions, and solving conflicts, teamwork becomes an important method for supporting product modularity. Conversely, the capacity of an information system can assist lateral channels for cross-boundary communication and conflict resolution during cooperation because information systems enable centralization and formalization of information from different sources. Therefore, we propose the following hypothesis:

H5: The impact of product modularity on MCC is enhanced by the interaction between teamwork and the information system capacity.

It was found that customization is associated with fewer layers of management[4,55] because the application of product modularity demands a flexible structure that quickly responds to the changes in customers' requirements. A flat organizational structure is widely regarded as an enabler of organizational flexibility in turbulent environments.[55] In a flat organization, there are fewer management layers in the vertical chain of command; thus, the hierarchical overload is reduced and decision making is moved to where the information exists.[24] The hierarchy of authority is decreased, and employees are empowered to interact and coordinate with others in horizontal channels at their own level. Without the need to endure a long vertical channel for approval, the effectiveness and efficiency of decisions concerning the module design and configuration are improved. Moreover, it is easier to develop lateral relations in a flat structure because the hierarchy of authority within the organization is simple. To a degree, the authority is decentralized to employees, and they are encouraged to develop lateral relations and to cooperate with others. Lateral relations are important for manufacturers because these relations enable them to improve the information processing capacity when they encounter complicated tasks.[30] Furthermore, the effects of a flat structure can be attenuated without the support of adequate information systems. In addition to facilitating horizontal communication and interactions, information systems also improve managers' spans of control. Through formalizing the information in the vertical channel in addition to the analytical power provided by information systems, managers' information processing capability is increased. Therefore, we propose the following hypothesis:

H6: The impact of the product modularity on MCC is enhanced by the interaction between the organizational structure flatness and the information system capacity.

3. Research Methodology

The research framework presented in Figure 1 and its related hypotheses were empirically tested by analyzing the data collected during the third round of the High Performance Manufacturing (HPM) project, which is a well-known multinational research project on manufacturing practices. The project included a group of members from different countries located in the U.S., Europe, and Asia. The data were collected by a group of faculty members in each country. The unit of analysis was the plant, and one plant per firm was considered. The data were collected using 21 different questionnaires that were distributed to 10 managers, 5 direct laborers, and 6 supervisors. At the end of the data collection, 238 plants actually responded; this represents a response rate of 65%, thereby reducing the need to check for non-response bias.[56]

The data were collected from medium to large size manufacturing plants (each with at least 100 employees) located in eight countries (the U.S., Germany, Sweden, Finland, Japan, South Korea, Australia and Italy). These countries were selected because they represent different national cultures, economic conditions and competitive environments around the world. The sample included plants in the electronics, machinery, and auto-supplier industries. The respondents in the HPM study were randomly selected from a master list of manufacturing plants in each of the countries and were approximately evenly distributed in the eight countries and three industries. The questions were answered by multiple informants, which greatly improved the reliability of the data and avoided the common method bias. The data were then aggregated to the plant level for analytical purposes. Table 1 provides a brief profile of the data, including the distribution of plants in different countries and industries.

Table 1. Sample Profile

Country	Industry			Total
	Electronics	Machinery	Auto supplier	
Japan	10	12	13	35
South Korea	10	10	11	31
Australia	10	7	4	21
U.S.	9	11	9	29
Finland	14	6	10	30
Germany	9	13	19	41
Sweden	7	10	7	24
Italy	10	10	7	27
Total	79	79	80	238

3.1. Measurement

The constructs of interest in this study were measured by multiple items. Most of these constructs have been used in previous rounds of the HPM study and their reliability and validity have been established. Perceptual items were measured using a Likert scale of 1 to 7, with 1 indicating “Strongly Disagree” and 7 indicating “Strongly Agree.” Certain items were reverse-scored to make their interpretation consistent with other measures. The measurement items and the sources of those scales are listed in Appendix A.

Six items were used to measure the four aspects of *mass customization capability*: high volume customization, customization cost efficiency, customization responsiveness, and customization quality.[7] *Product modularity* was operationalized in the context of whether the products were designed to be common and reconfigurable modules.[57] *Information system capacity* was measured in terms of the investments in the information systems used in the areas of inventory management, order management, design (CAD/CAE), product data management, and groupware tools (e.g., Lotus Notes).[48] *Multifunctional employees* were operationalized in the form of the degree of cross-training and the number of different tasks employees could perform.[58] *Teamwork* was operationalized by ascertaining whether small groups or teams were used within the firm to solve problems.[59] Finally, *organizational structure flatness* was measured by the number of management tiers or levels in the organizational hierarchy.[60,61] The items used to develop these measures were included on multiple questionnaires, which, in turn, helped to avoid problems caused by single-respondent bias.[62] Because non-scale items were used to measure the information system capacity (1=‘does not meet needs’; 4=‘meets needs extremely well’), we standardized the items.

3.2. Reliability and validity

To validate the measures used in this study, we first conducted an exploratory factor analysis to assess the uni-dimensionality. In all cases, an eigenvalue in excess of 1.00 was used to determine which factors would be retained, and a factor loading cutoff of 0.50 was used to ensure that each item contributed significantly to its factor.[63] Table 2 shows the results of the principal component factor analysis with Varimax rotation. The factor analysis suggested that all items met the cut-off criteria. Second, Cronbach’s alpha was used to evaluate construct reliability.[56] Table 3 shows that the scales are reliable because the values of Cronbach’s alpha are larger than the 0.60 threshold value recommended by Flynn et al.[56]

Table 2. Factor Analysis

	Organizational Structure Flatness Eigenvalue=5.454	Teamwork Eigenvalue=2.371	Information System Capacity Eigenvalue=2.214	Multifunctional Employee Eigenvalue=1.877	Product Modularity Eigenvalue=1.315
OSF1	**.872**				
OSF2	**.870**				
OSF3	**.866**				
OSF4	**.836**				
OSF5	**.786**				
TW1		**.867**			
TW2		**.839**			
TW3		**.817**			
TW4		**.638**			
ISC1			**.748**		
ISC2			**.679**		
ISC3			**.656**		
ISC4			**.655**		
ISC5			**.616**		
MFE1				**.838**	
MFE2				**.793**	
MFE3				**.792**	
PM1					**.859**
PM2					**.833**
PM3					**.740**
Total variance explained	27.268%	11.855%	11.069%	9.348%	6.573%

Table 3. Reliability analysis

Construct	**Number of items**	**Cronbach's alpha**
Mass customization capability (MCC)	6	0.737
Product Modularity (PM)	3	0.744
Information system capacity (ISC)	5	0.696
Organizational structure flatness (OSF)	5	0.921
Multifunctional employee (MFE)	3	0.831
Teamwork (TW)	4	0.844

Third, we constructed a confirmatory factor analysis (CFA) model using the LISREL 8.54 program to assess the convergent validity. In the model, each item was linked to its corresponding construct, and the covariance among those constructs were freely estimated. The model fit indices were **Error! Reference source not found.**(284) = 460.2

(p=0.000), Non-Normed Fit Index (NNFI) = 0.95, Comparative Fit Index (CFI) = 0.95, and Root Mean Square Error of Approximation (RMSEA = 0.054), which are better than the threshold values recommended by Hu & Bentler.[64] Generally, a construct that has a loading of indicators of at least 0.5, a significant t-value ($t > 2.0$), or both is considered to be convergently valid.[65] Because our model satisfied this requirement, convergent validity was achieved in our study. Finally, we developed a constrained CFA model for each possible pair of latent constructs in which the correlations between the paired constructs were fixed to 1. We compared this model with the original unconstrained model in which the correlations among the constructs were freely estimated. A significant difference of the Chi-square statistics between the constrained and unconstrained models would indicate high discriminant validity.[65] In our study, all constructs were discriminant at the 0.01 level. Therefore, discriminant validity was achieved in our study.

4. Analysis and Results

In the following analyses, the summated scale was used for each construct. Table 4 shows the correlation among these constructs.

We included three control variables in our analysis: country, industry, and plant size. Country and industry have been suggested as institutional factors that explain the adoption of various manufacturing innovations and practices.[66] The economic environment of different countries may influence the manufacturing and supply chain concepts used by the company in the creation of its mass customization capability. Prior studies have indicated that the industry type has an effect on the operations in manufacturing organizations (e.g., Refs. 2 and 9). The available technologies and competition intensity in a given industry may affect managers' decisions regarding manufacturing practices. Large companies are more likely to have a higher MC capability than small companies due to the additional resources available. Thus, we also controlled for the effects of company size by measuring plant size as the natural logarithmic transformation of the number of employees.

We conduct an ordinary least square regression in which MCC was the dependent variable and the control variables were independent variables. The standardized residual of this regression was saved and used as a dependent variable for further analysis so that the effects of control variables could be eliminated. The residual analysis revealed that one observation was an outlier, which was eliminated from further analysis.

Table 4. Correlation matrix

	MCC	PM	ISC	MFE	SF
Product modularity (PM)	**.222****				
Information system capacity (ISC)	-.040	.033			
Multifunctional employees (MFE)	**.207****	.078	-.043		
Organizational structure flatness (OSF)	**.212****	-.040	-.072	**.436****	
Teamwork (TW)	**.156***	.066	-.010	**.443****	**.350****

*** p<0.01; ** p<0.05; * p<0.1

Table 5. Regression analysis for moderating effect of information system capacity

	Base model			**Full model**		
Independent variables	**Beta**	**P-value**	**VIF**	**Beta**	**P-value**	**VIF**
Product modularity (PM)	.208***	.001	1.001	.224***	.001	1.023
Information system capacity(IS)	-.003	.959	1.001	.033	.622	1.112
PM*IS				.117*	.087	1.136
R^2 (adj. R^2)	**0.043 (0.035)**			**0.055 (0.043)**		

*** p<0.01; ** p<0.05; * p<0.1

Hierarchical regression analyses were used to test the first three hypotheses (Table 5). In the base model, we explored the main effects of the product modularity (PM) and the information system capacity (ISC) on the MC capability (MCC). Then, we added the interaction term in the model to test the moderating effect of the information system capacity (ISC). Tables 6 through 8 contain the moderated multiple regression results for multifunctional employees (MFE), teamwork (TW), and organizational structure flatness (OSF), respectively. For each regression, the independent variables included the product modularity, the information system capacity, the social dimensions (MFE, TW, and OSF), and their interactions. The regression models are shown below:

Model1: $MCC = a_{11} + b_{11}PM + b_{12}ISC + e$
Model 2 : $MCC = a_{21} + b_{21}PM + b_{22}ISC + b_{23}PM * ISC + e$
Model 3 : $MCC = a_{31} + b_{31}PM + b_{32}ISC + b_{33}MFE + b_{34}PM * ISC + b_{35}PM * ISC * MFE$
$+ e$ Model 4 : $MCC = a_{41} + b_{41}PM + b_{42}ISC + b_{43}TW + b_{44}PM * ISC + b_{45}PM * ISC * TW$
$+ e$ Model 5 : $MCC = a_{51} + b_{51}PM + b_{52}ISC + b_{53}OSF + b_{54}PM * ISC + b_{55}PM * ISC *$
$OSF + e$

The regression results in the base model of Table 5 revealed that the product modularity significantly contributed to MCC, whereas the information system capacity did not have a significant effect. Thus, H1 is supported by the data and H2 is not. However, the significant interaction terms in the full model of Table 5 suggest that although the information system capacity does not have a direct effect, it improves MCC by enhancing the impacts of the product modularity. Thus, H3 is supported. The significant three-term interaction in Table 6 shows that the impact of the product modularity on MCC is higher when the organization uses a high level of multifunctional employees with a high information system capacity. Based on the results shown in Table 7 and Table 8, we find that the impact of the product modularity on MCC is enhanced when the manufacturer implements teamwork and flat organizational structures with a high information system capacity. Therefore, H4, H5, and H6 are all supported.

Table 6. Regression analysis for moderating effect of multifunctional employees

Independent variables	**Beta**	**p-value**	**VIF**
Product modularity (PM)	.299***	.000	1.056
Multifunctional employees (ME)	.188***	.003	1.015
Information system capacity (ISC)	.026	.691	1.129
PM * ISC	.108	.106	1.139
ME*PM*ISC	.120*	.062	1.052
R^2(Adj. R^2)	**0.101 (0.081)**		

*** $p<0.01$; ** $p<0.05$; * $p<0.1$

Table 7. Regression analysis for moderating effect of teamwork

Independent variables	Beta	p-value	VIF
Product modularity (PM)	$.226^{***}$	.001	1.036
Teamwork (TM)	$.118^{*}$	.065	1.011
Information system capacity (ISC)	.027	.688	1.114
PM * ISC	.057	.438	1.362
TM*PM*ISC	$.125^{*}$	.076	1.232
R^2(Adj. R^2)	**0.080 (0.060)**		

*** p<0.01; ** p<0.05; * p<0.1

Table 8. Regression analysis for moderating effect of structure flatness

Independent variables	Beta	p-value	VIF
Product modularity (PM)	$.249^{***}$	.000	1.044
Organizational structure flatness (OSF)	$.146^{**}$	.021	1.010
Information system capacity (ISC)	.041	.534	1.121
PM * ISC	$.128^{*}$	.056	1.139
OSF*PM*ISC	$.127^{**}$	.046	1.022
R^2(Adj. R^2)	**0.094 (0.074)**		

*** p<0.01; ** p<0.05; * p<0.1

5. Discussion

Ketokivi & Schroeder[66] advised that operations management researchers should address contingencies in their studies. In accordance with this suggestion, we focused on the contextual factors that support product modularity from both the information processing theory and the socio-technical systems perspectives. The effectiveness of product modularity depends on whether manufacturers can capture the commonalities of the demands and satisfy them by configuring the modules. Manufacturers need to respond flexibly and quickly to demand changes by rescheduling and cooperating in the design and production of the module. Thus, the introduction of a product modularity and mass customization paradigm significantly increases the quantity and complexity of the information processed by the organization.[18] One means to address this problem is to increase the information system capacity.[48]

Our results show that although the information system capacity does not directly improve the mass customization capability, it can enhance the effectiveness of product modularity on mass customization. First, the information system capacity facilitates mass customizers to solicit customer needs quickly and accurately. The identification of customer needs is a prerequisite to mass customization.[4] Additionally, product modularity highly depends on the accurate recognition of customer needs. Second, the information system capacity helps the organization and employees to easily assimilate external information. Product modularity requires the design of appropriate modules according to customer demands and a selection of the appropriate process to make these modules available. All these activities will increase the quantity and complexity of information within the organization. Without the support of the information system capacity, manufacturers will be overwhelmed by the huge quantity of complicated information. Thus, the information system capacity provides an efficient infrastructure for mass customizers to take full advantage of the product modularity in terms of design and process.

Our findings also reveal that an organization’s human and social systems play important roles in enhancing the effectiveness of product modularity. First, from the socio-technical systems perspective, the social system must adapt to the technical system to make the latter more effective.[26] Through cross-training, teamwork, and a flattened organizational structure, the flexibility and responsiveness of the human resources are improved. The employees can then better satisfy the customized demands using the existing technical system. Thus, a suitable human and social system is beneficial for realizing the potential of an information system. Second, multifunctional employees, teamwork and an organizational structure flatness are typical alternatives to information processing for improving the information flow and processing.[24,30] Teamwork can facilitate lateral communications among employees. Multifunctional employees can be considered as a type of slack resource that enables the employees to process information more efficiently and effectively.[34] A flat organizational structure can shorten the communication line within the organization, thereby accelerating information processing and decision making and increasing the flexibility of the organization and process. Thus, with the support of the information system capacity, these three contextual factors can increase the benefits provided by product modularity to the mass customization capability. This study contributes to the MC literature by linking the information processing alternatives with MCC and exploring the contextual factors that enhance the impact of the product modularity on MCC based on the information processing theory.[20,24] Moreover, although certain empirical research studies have focused on the impact of both social and technical-oriented practices on MCC (e.g., Refs. 2, 6, 7, and 13), there is no research that explores the match between these two sets of practices. In this study, we investigated the benefits of matching an information system with the three social-oriented practices based on the socio-technical systems theory.[25,26] Our study enhances the understanding of MC through the combination of the information processing theory and the socio-technical systems theory.

In practical terms, our study also has important managerial implications. First, our study suggests that manufacturers can improve MCC by using product modularity, the effectiveness of which can be enhanced by increasing the information processing capability. Second, our results suggest that the information system and social-oriented practices, such as multifunctional employees, teamwork and organizational structure flatness, are complementary to each other. When designing an organization, managers should develop these practices simultaneously. Third, managers must develop an information system foundation to fully exert the effects of the aforementioned social practices and the product modularity.

6. Conclusions

Based on the information processing theory and the socio-technical systems theory, we explored the contextual factors that enhance the impact of product modularity on MCC improvement. First, we identified several contextual factors (information system capacity, multifunctional employees, teamwork, and structure flatness) that enhance the impact of product modularity on MCC based on the information processing theory. Second, we found that although the information system does not directly improve MCC, it plays its role by enhancing the impact of product modularity. Third, based on the argument of the socio-technical system theory, we found that the combination of social-oriented practices and an information system also increases the impact of the product modularity on MCC.

As with any study, there are several limitations that may be addressed in future research. First, the focus of this study is manufacturer's internal operations. However, as suggested by Galbraith,[20] an organization can also improve its information processing capability through environmental management.[30] This work can be extended through the linkage of supply chain management practices with information processing capabilities and by accommodating complexity.[34] Second, we focused solely on product modularity in this work. Researchers have suggested that the concept of modularity can be extended to process design, organization design, and supply chain design. These forms of modularity are important for MCC (e.g., Refs. 10, and 12-14). The effect of contextual factors on the impact of other forms of modularity on MCC is also an interesting topic for future studies.

Appendix A.

Mass customization capability

MCC1: We are highly capable of large scale product customization
MCC2: We can easily add significant product variety without increasing cost.
MCC3: Our setup costs, changing from one product to another, are very low
MCC4: We can customize products while maintaining high volume.
MCC5: We can add product variety without sacrificing quality.
MCC6: Our capability for responding quickly to customization requirements is very high.

Organizational Structure Flatness

SF1: Our organizational chart has many levels. (Reverse)
SF2: There are many levels between the lowest level in the organization and top management. (Reverse)
SF3: There are few levels in our organizational hierarchy.
SF4: Our organization structure is relatively flat.
SF5: Our organization is very hierarchical (Reverse)

Multifunctional Employees

MFE1: Employees at this plant learn how to perform a variety of tasks
MFE2: Employees are cross-trained at this plant, so that they can fill in for others, if necessary
MFE3: At this plant, each employee only learns how to do one job (Reverse).

Teamwork

TW1:Our plant forms teams to solve problems
TW2: Problem solving teams have helped improved manufacturing processes at this plant
TW3: We don’t use problem solving teams much in this plant (Reverse)
TW4:Employee teams are encouraged to try to solve their own problems, as much as possible

Information system capacity

ISC1: Order management
ISC2: Design (CAD, CAE)
ISC3: Inventory management
ISC4: Product data management
ISC5: Groupware tools (e.g. Lotus Notes)

Modularity of products

MP1: Our products are designed to use many common modules

MP2: Our products are modularly designed, so they can be rapidly built by assembling modules.

MP3: We have defined product platforms as a basis for future product variety and options.

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