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Impact of product development efforts on product introduction and product customization abilities: investigating the effects of product design complexity and product development order winners

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Abstract

This paper investigates the impact of efforts in new product development-manufacturing integration (NPDMI) on new product introduction (NPI) and product customization (PC) abilities and the moderating effects of product design complexity and importance of new product development order winners (NPIOW) on the above relationships. The results from the data on 136 Indian manufacturing plants show that NPDMI, product design complexity and NPIOW all have significant positive impact on NPI and PC abilities. Importance of NPIOW has a positive moderating effect on the relationship between NPDMI and PC ability change but product design complexity demonstrate no such effect on the above relationships.

Keywords: new product development-manufacturing integration, product design complexity, importance of product development order winners

Introduction

Integration of design and manufacturing has been considered to play a key role in improving new product ability and the outcomes of the development effort. Bergen and McLaughlin (1988) noted that product performance is significantly enhanced if production is involved in product design. Indeed, manufacturing organizations have been taking efforts to improve internal collaboration between design and manufacturing. But, there is no clear empirical evidence of the NPD-manufacturing integration efforts on new product introduction (NPI) and product customization (PC) abilities. Langowitz (1989) found that the presence or absence of manufacturing personnel on NPD design teams was not significantly associated to smoothness of new product introduction. Swink (1999) in his study of 91 completed NPD projects found that the association between manufacturing involvement and new product manufacturability is marginally

significant. Troy et. al. (2008) noted that though cross-functional integration may have a direct impact on success of new products, the combination of integration with other variables may be of greater importance. Antonio et. al. (2009) studied the individual effects as well as interaction effects of product modularity and internal integration on order winners. The authors reported that that better internal integration can significantly improve product innovativeness, product quality, delivery, flexibility and customer services, while a high level of product modularity enhances product innovativeness, flexibility and customer services. This study also showed that internal integration and product modularity can interact to improve product innovativeness and product quality. Danese and Filippini (2010) studied the impact of modularity on new product development (NPD) time performance and used supplier and inter-functional integration as moderating variables. The above studies are relevant when product architecture choice in terms of degree of modularity and integrality are the decisions which firms are considering while developing new products. But, when a firm is planning to invest in time and effort in improving NPD-manufacturing integration, with a given level of product design complexity, understanding the impact of such integration efforts on NPI and PC abilities will be of relevance to researchers. Moreover, product design complexity and importance of order winners can influence the NPD-manufacturing integration and NPI (Sosa et. al., 2004) , PC(Acur et.al., 2003) relationships. But, there is limited research studying the above moderating relationships. Thus, there is a need to study whether product development efforts related to NPDMI improve NPI and PC abilities and whether degree of product design complexity and importance of order winners influence the above relationships.
Hence, the purpose of this study is to investigate the effect of NPD and manufacturing integration efforts (NPDMI) on NPI and PC abilities and the incremental and moderating effects of product design complexity and importance of new product development order winners on the NPDMI-NPI ability and on NPDMI-PC ability relationships.

Literature Review and research hypotheses

Relationship between NPD-Manufacturing integration efforts and NPI and PC abilities

Cross-functional integration (i.e., the degree of interaction, communication, information sharing, or coordination across functions) has been identified as a key driver of new product success (Griffin and Hauser 1996). Integration through teams accelerates the new product process because it can eliminate steps, prevent delays, present opportunities for simplification and parallel processing, and speed operations launching (Wheelright and Clark, 1992). Manufacturing involvement in the development process is necessary to enable it to initiate changes in manufacturing process technology and align its technological abilities and constraints within the product specifications. Similarly, unique capabilities of manufacturing process technology also need to be considered by the design team for decisions related to the complexity and variety of components within product families. Such integration efforts will ensure that project performance goals are met, delays in the development process can be prevented, and the product's time to market can be reduced (Mishra and Shah, 2009). Multiple authors have validated the benefits of this integration like Sherman et al. (2000) found for reduction of development cycle time and Swink and Calantone (2004) for product design quality. Ahmed et. al. (2010) demonstrate that interfunctional design coordination mediates the relationship between product modularity and mass customization ability. This leads to the first two hypothesis of our research

H1a: Higher NPD-Manufacturing integration efforts will have positive impact on NPI ability and H1b: Higher NPD-Manufacturing integration efforts will have positive impact on PC ability

Moderating effects of product design complexity on NPD-Manufacturing integration efforts

Product modularity helps break down communication barriers by creating a common language (Danese and Romano, 2004) and facilitates NPD-Manufacturing integration. Jacobs et. al. (2007) found that product modularity had a significant effect on design integration. Antonio et. al. (2009) showed that internal integration and product modularity complement each other to enhance competitive capabilities and helps to develop innovative and quality products. Tu et. al. (2004) showed that modularity based manufacturing practices which includes product and process modularity and dynamic teaming have positive influence on mass customization ability. Sosa et. al. (2004) showed through case studies that an appropriate level of integration across module teams is required to maintain the compatibility of product modules, which is crucial if a company is to deliver a new product quickly and flexibly. Thus, we can hypothesize that while modularity and NPD-Manufacturing integration may play complementary role in improving new product introduction and product customization abilities, higher product design complexity in terms of integrated design may have a negative impact on how NPD-manufacturing integration efforts impact new product introduction and product customization abilities. Thus, we can hypothesize as follows;

H2a: Product design complexity and NPDMI efforts will interact to have a negative impact on NPI ability

H2b: Product design complexity and NPDMI efforts will interact to have a negative impact on PC ability

Moderating effects of product development order winners on NPD-Manufacturing integration efforts

Manufacturing executives continuously look at improvement programmes as the place where manufacturing strategy should be operationalized (Kim and Arnold, 1996). Kaplan and Norton (2001) observed that people can only commit to a strategy if they believe in it. In order to believe in a strategy, people must be convinced that they will achieve their (business) goals as a result of pursuing this strategy (Acur et.al., 2003). Thus, the importance of product development order winners should ensure that the manufacturing strategy gets executed through NPD-Manufacturing integration and it will indeed lead to improvement in NPD abilities. Thus, importance of product development related order winners like frequent launch of new products, launch of innovative products and customized products are expected to have a positive influence on the extent to which NPD-manufacturing integration efforts influence NPI and PC abilities, leading to our third hypotheses.

H3a: Product development order winners and NPDMI efforts will interact to have a positive impact on NPI ability; H3b: Product development order winners and NPDMI efforts will interact to have a positive impact on PC ability

Methodology

Data Collection and sample

The study uses data from the 6th round of International Manufacturing Strategy Survey (IMSS). Data was collected in 2013 by an international team of researchers working in different universities all over the world and includes responses from manufacturing plants operating in different sectors such as manufacturing of fabricated metal products except machinery, computer, electronic and optical products, electrical equipment, other machinery and equipment, motor vehicles, trailers and semi-trailers and other transport equipment. The responses are from manufacturing plants operating in multiple countries across continents but this data set uses 136 valid responses obtained from manufacturing plants in India. A database of 500 companies was created using Prowess database comprising all the sectors which are studied and were contacted to participate in the survey. 162 responses were obtained but 26 were rejected because of people with appropriate designation not filling up the survey. Non-response and late response bias was checked using average Return on Assets (ROA) and average Return on Sales (ROS) and no significant difference found between the responding-non-responding and the early-late respondent groups. The percentage break-up of the sectors among the valid 136 responses are 11.03, 31.62, 19.85, 15.44, 13.97 and 8.09 respectively.

Research variables and measures

The items used in the present research are a sub-set of the entire IMSS. NPD-manufacturing integration is a multi-faceted construct and involves the following items:

1) Design integration: This construct includes modular design, standardization, Design for manufacturing and Assembly. A modular architecture is a form of product design in which loose coupling is achieved through standardized component interfaces, which enables the production of a large number of end items and is one of the precursors to mass customization (Worren et al., 2002). Standardization refers to the use of standard procedures, materials, parts, and/or processes for designing and manufacturing a product (Droge et. al., 2004). There is a consensus among several researchers that standardization and product modularity are conceptually inseparable (Ulrich, 1995; Meyer and Lehnerd, 1997; Jacobs et. al., 2007). Design for manufacturing (Paashuis and Boer, 1997; Schilling and Hill, 1998, Droge et. al., 2000; 2004) and Design for Assembly (Paashuis and Boer, 1997) are other techniques used for design integration.

2) Organizational integration: Specialization can lead to functional isolation and the rise of conflicting perspectives and goals (Swink, 2000). Cross-functional teams are considered fundamental for overcoming communication barriers established by functional silos (Swink, 1996). Combination of broad jobs and cross training influences new product development and introduction timing, because employees gain a clearer understanding of the interrelationships among tasks and processes. Secondment and co-location are also considered as important organizational means to link groups of people (Paashuis and Boer, 1997).

3) Technological integration: Internal integration cannot be fully achieved by the isolated use of boundary spanning practices, but instead requires the ‘bundling’ of management tools with technology tools such as CAD and CAM (see e.g., Smith and Reinertsen, 1998, Droge et.al., 2000).

4) Integrating tools and techniques: Tools like Quality Function Deployment, Failure Mode and Effect Analysis and Rapid Prototyping can be effectively used for NPDMI (Paashuis and Boer, 1997; Schilling and Hill, 1998).

5) Informal means of communication: Product design and development efforts involve many different specialists with high degree of dependence amongst each other to complete their respective tasks. More and better communications between design and manufacturing leads to better insights into the other function’s role (Vandevelde and van Dierdonk, 2003). Early and regular communication between design and manufacturing reduces the amount and size of time-consuming problems (Dean and Susman, 1989), modifications and rework. Regular discussion of problems, presentation of the designer’s ideas to manufacturing and feedback from manufacturing on these presentations play an important role in developing a product with the possibilities and requirements of manufacturing (Rosenthal and Tatikonda, 1992).

6) Communication technologies: Information sharing during product development can be through use of communication technologies like video-conferancing, web-meetings etc

7) Process standardization: Use of formal processes for standardization has also been found to have positive impact of NPD performance (Tatikonda and Montoya-Weiss, 2001)

All the above items which constitute the NPD-Manufacturing integration construct were measured on a 1-5 scale for efforts in the last 3 years and current level of implementation. Product design complexity was measured on a 1-5 scale where '1' indicates modular product design and '5' indicates integrated product design. The importance of order winners related to new products are assessed using 1-5 scale where '1' indicates 'not important' and '5' indicates 'very important'.

The order winners considered for new product introduction are 'offer more product customization', 'offer new products more frequently' and 'offer products that are more innovative'. These form the NPIOW construct. Note, these are only sub-set of all order winners considered in the IMSS. To test the unidimensionality of the different constructs, a principal component factor analysis by Varimax rotation of factors was conducted. Table 2 shows the results of the factor analysis after Varimax rotation of factors and the reliability test results by Cronbach's α. The items comprising the constructs of NPD-manufacturing integration efforts and NPI order winners (NPIOW) have high factor loadings (the lowest being 0.568 while all others are 0.68 and above), thus demonstrating high construct validity. Further, the off-factor loadings for the other items considering each factor are low (the highest being 0.35 while all others are 0.319 and below), providing evidence of discriminant validity. Also, Cronbach α values for NPD-manufacturing integration efforts and NPIOW are 0.852 and 0.733 respectively, showing high reliability. Product design complexity as a single variable also has high factor loading of 0.92. Confirmatory Factor Analysis (CFA) using AMOS with covariance matrix as input was also conducted to examine unidimensionality, convergent and divergent validity of NPIOW and NPDMI. The overall fit of the CFA was satisfactory. The results were chi square/df =1.576, comparative fit index of 0.956, root mean square of approximation of 0.065. All the estimates exceeded 0.5 and all the corresponding 'p' values were significant at 0.001 significance level. These tests confirmed convergent validity. Table 2 shows the validity tests of the measures.

Data analysis and results

Table 3 shows the basic statistics of the constructs with inter-item correlations. To test the hypotheses, we ran hierarchical regression analysis. In the base model (Model 1), control variables of firm size, industry sector and nature of business (i.e. business-to-business or business-to-customers) were inserted. Firm size was inserted in the model as dummy variables with different revenue range categories, industry sector was also inserted as dummy variables. Percentage of sales to different types of customers i.e manufacturers of sub-systems, manufacturers of finished products, wholesalers/distributors and end users were used to identify companies whose larger percentage of sales come from industrial customers and from wholesalers or end users. Thus, a single dummy variable (btob) was used to capture this. For the dummy variables, 'indicator coding' was used which implies that the regression coefficients are deviations from a comparison group.

Table 2 – Validity test of measures

Measurement Item	NPD-Manufacturing Integration efforts	NPI Order Winners	Product design complexity
Cronbach's α	0.852	0.733	
Indicate the efforts put in the last 3 years into implementing			
Informal mechanisms such as direct, face to face communication, informal discussions, ad-hoc meetings	**0.568**	-0.028	0.350
Design integration between product development and manufacturing through platform design, standardization and modularization, design for manufacturing, design for assembly	**0.782**	0.021	-0.027
Organizational integration between product development and manufacturing through cross-functional teams, job rotation, co-location, role combination, secondment and co-ordinating managers	**0.680**	0.192	0.125
Technological integration between product development and manufacturing through CAD-CAM, CAPP, CAE, PLM	**0.781**	-0,075	-0.202
Integrating tools and techniques such as FMEA, QFD, Rapid Prototyping	**0.651**	0.319	0.218
Communication technologies such as teleconferencing, web-meetings, intranet and social media	**0.811**	0.135	0.042
Forms of process standardization such as stage-gate process, design reviews and performance management	**0.688**	0.221	0.228
Consider the importance of following attributes to win orders from major customers			
Offer more product customization	0.093	**0.802**	0.060
Offer new products more frequently	0.162	**0.772**	-0.111
Offer products that are more innovative	0.044	**0.816**	0.129
Describe complexity of dominant activity(modular_integrated product design)	0.093	0.046	**0.920**
Initial eigen values	4.057	1.787	1.041
Percentage of variance of the rotated factors	36.878	16.241	9.467

Model 1 in Table 4 represents the first step of the hierarchical regression for NPI ability change. Industry code 2 is significant at 0.1 level for this base model. In model 2, NPDMI, product design complexity and NPIOW are added. In models 3 and 4 interaction between NPDMI and NPIOW are added in the last step respectively. Thus, only one interaction term is added at a time to minimize multicollinearity (Parthasarathy and Hammond, 2002; Danese and Filippini, 2010). Also, to avoid multi-collinearity we used mean-centred data as suggested by multiple authors. Table 5 shows the results of the identical models as described above but with product customization ability as the dependent variable.

Table 3: Basic statistics and correlational analysis

				Correlations				
Variables	Mean	SD	N	NPD-Manufacturing integration efforts	NPIOW	Product design complexity	NPI ability change	Product customization ability change
NPD-Manufacturing integration efforts	3.710	0.688	133	1	0.294***	0.207**	0.474***	0.512***
NPIOW	3.919	0.876	136		1	0.122	0.358***	0.261***
Product design complexity	3.621	1.238	132			1	0.296***	0.286***
NPI ability change	3.463	1.095	135				1	0.711***
Product customization ability change	3.378	1.092	136					1
Note: Significance at: 0.05**, 0.01***								

The results show that NPDMI, product design complexity and NPIOW are all individually significant, the interaction between NPDMI and NPIOW is significant at 0.10 level for PC ability change but not significant for NPI ability change. The interaction between NPDMI and product design complexity is not significant for both NPI and PC ability changes. Thus, we can conclude that importance of NPIOW has a positive moderating effect only on the relationship between NPDMI and PC ability change, thus supporting hypotheses 3b but we could not find support in favour of the hypotheses 2a and 2b about the moderating effect of product design complexity on the above relationships (hypothesis 3a).

Table 4: Hierarchical regression results for NPI ability change

	Model 1	Model 2	Model 3	Model 4
Constant	3.998***	3.859***	3.858***	3.884
Industry 1	-0.548	-0.380	-0.344	-0.378
Industry 2	-0.638*	-0.660	-0.650	-0.656
Industry 3	-0.099	-0.075	-0.064	-0.085
Industry 4	-0.444	-0.323	-0.307	-0.399
Industry 5	0.208	0.014	0.063	-0.013
Revenue 1	-0.169	-0.092	-0.022	-0.113
Revenue 2	0.042	0.204	0.219	0.187
Revenue 3	-0.025	0.031	0.030	-0.008
Revenue 4	-0.255	-0.167	-0.188	-0.221
btob	-0.268	-0.225	-0.252	-0.231
NPDMIcurrentlevel	0.279**	-0.194	-0.202	-0.151
NPDMI		0.309*	0.336**	0.306*
Productdesign complexity		0.204***	0.191***	0.208***
NPIOW		0.428***	0.408***	0.487***
NPDMI*productdesign complexity			-0.110	
NPDMI*NPIOW				0.095
R^2	0.163	0.347	0.356	0.354
Adjusted R^2	0.086	0.269	0.273	0.271
ΔR^2		0.184	0.009	0.008
Significance of F change	0.024	0.000	0.201	0.245

Significance at: 0.1*, 0.05**, 0.01***

Managerial implications and conclusion

The results have important managerial implications for Indian manufacturing industry. The positive moderating effect of importance of NPIOW on NPD-manufacturing integration efforts for PC ability suggest that the leadership team of the organization should communicate the importance of product development related order winners to the NPD and manufacturing teams in their communications and the strategic direction provided by such communication can have a positive impact in improving PC abilities through NPD-Manufacturing integration efforts. The apparent lack of moderating effect of product design complexity implies that high product design complexity in terms of integral design will necessarily not undermine the impact of NPD-manufacturing integration efforts on NPI and PC abilities and can potentially encourage firms to seek improvements in the above two abilities. Significant positive effect of product design complexity on both NPI ability and PC ability changes suggest that higher product design complexity is forcing companies to change their NPI and PC abilities.

While the existing literature has studied the role of internal and external integration efforts on product modularity and product development performance, there is limited research on how product design complexity and NPIOW influence the relationship between NPD-manufacturing integration efforts and NPI, PC abilities. Thus, this study makes unique contribution in studying the above effects.

Table 5: Hierarchical regression results for PC ability

	Model 1	Model 2	Model 3	Model 4
Constant	3.315***	3.093***	3.093***	3.133***
Industry 1	0.023	0.245	0.263	0.248
Industry 2	-0.268	-0.250	-0.245	-0.243
Industry 3	0.555	0.535	0.541	0.519
Industry 4	0.148	0.271	0.279	0.150
Industry 5	0.408	0.213	0.238	0.171
Revenue 1	0.510	0.636*	0.672*	0.604*
Revenue 2	0.188	0.369	0.376	0.342
Revenue 3	0.134	0.270	0.270	0.209
Revenue 4	-0.042	0.138	0.127	0.053
btob	-0.339*	-0.230	-0.243	-0.239
NPDMICurrentlevel	0.369***	-0.117	-0.121	-0.048
NPDMI		0.417**	0.430***	0.413***
Productdesign complexity		0.228***	0.221***	0.234***
NPIOW		0.264**	0.253**	0.356***
NPDMI*productdesign complexity			-0.056	
NPDMI*NPIOW				0.150*
R^2	0.204	0.361	0.364	0.380
Adjusted R^2	0.130	0.284	0.281	0.300
ΔR^2		0.157	0.002	0.019
Significance of F change	0.003	0.000	0.515	0.062

Significance at: 0.1*, 0.05**, 0.01***

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