Production Planning & Control,
Vol. 15, No. 4, June 2004, 422–434

Investigating the role of IT in customized product design

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Keywords Customization, product design and development, information technology

Abstract. Realizing product customization as 'just a mouse click away' is the ultimate dream of many organizations and customers. To date though, mass customization is generally delivered through standardized products or custom-assembly of standardized components – often neglecting the product development aspect of customization through providing custom-designed products. In this paper we address this gap, and in particular investigate – both theoretically and empirically – the role of IT in product development-related customization. We revert to the automotive industry, which although it has long progressed beyond 'any colour as long as it is black', still offers only limited customization possibilities to its customers.

1. A shift in competitive strategy

Mass customization is a key challenge for most industries. Some do cope very well, using a range of strategies such as modularity or late configuration. Dell, for example, assembles computers to order based on a modular structure and standardized components. HP printers, which basically are standard products, are configured to order by inserting the right power cord and manual according to the country they are delivered to (Feitzinger and Lee 1997). Customization so far though has focused around existing products, or products derived from standardized components, and hence centre on 'existing' product designs. The product development (PD) aspect

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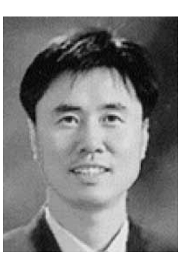

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Production Planning & Control ISSN 0953–7287 print/ISSN 1366–5871 online © 2004 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/0953728042000238782

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for providing 'truly' customized products has been neglected.

In this paper we intend to address this gap by examining the efficacy of customized product design and exploring the role of information technology (IT) in facilitating this kind of customization. In doing so, we lay the groundwork for an empirical investigation for the connection between IT usage in a manufacturing firm and its product design and development capability, and consequently its ability to provide customized product designs. We revert to the automotive industry, where manufacturers have long gone beyond 'any colour as long as it is black', yet still only offer limited customization possibilities to the customer.

Much of the attention in manufacturing is shifting 'upstream', towards PD, as the last decade witnessed remarkable improvements in production quality, efficiency and lead-time reduction. This move is consistent with the transformation of competitive structure from mass production in the 1950s into mass customization in the 21st century, as shown in figure 1. For example, during the 1950s, mass production was the prevalent competitive strategy of most manufacturing companies. As in the days of Henry Ford, this strategy entailed labour specialization and the acquisition of large (and dedicated) production equipment (i.e. hardware), where manufacturers were the dominant power in the supply chain (i.e. internal focus). Most of the components were still made in-house, and the few suppliers had very limited involvement in product/component design and development.

As the Japanese car manufacturers gained ground in the US market during the 1980s, quality and speed of

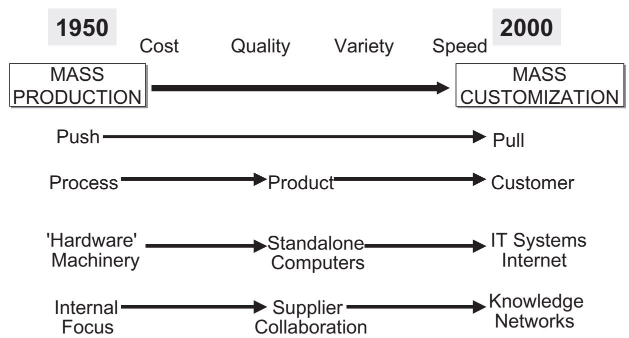

Figure 1. The transformation of competitive strategy.

new product introductions became major competitive issues and the locus of competition shifted from process orientation to product orientation. This period marked the introduction of early IT tools (i.e. CAD systems, numerical control, FEM analysis tools and other standalone software tools) and more supplier involvement. Yet, it was not until the end of the 20th century that the end customer became the focus of attention. In addition to product specification, quality and price, firms started competing on the basis of time (Stalk and Hout 1990), gaining competitive advantage through their ability to serve customers quicker and cater closely to their diverse product needs and demands. Consequently, the next generation of competition between firms was often referred to as 'mass customization' (Pine 1993), which initially was brought forward as an oxymoron by Davis (1987) – to highlight the contradictory nature of 'mass production' and 'product customization' – but was soon accepted as a key challenge in manufacturing.

How to couple production systems geared towards efficient mass production with the increasing demand for customization is currently one of the most pressing concerns of automotive manufacturers. In particular, many OEMs (original equipment manufacturers) investigate how to effectively build-to-order, rather than to forecast (Holweg and Pil 2001). GM, for example, is developing its order-to-delivery program by leveraging its advanced IT-enabled design-and-supply chain to build and deliver custom cars in 15-20 days, compared to the industry average of 50-80 days (Milligan 2000). GM is not the only one trying to win this game. In a similar vein, DaimlerChrysler's FastCar and Ford's ConsumerConnect initiatives are designed to interconnect their design, manufacturing and marketing through advanced IT systems, which will provide real-time transparency to the product development process and allow for realizing profitable mass-customized vehicles.

In the next section we will examine different mass customization strategies and their evolution, with a particular emphasis on their application in the motor industry. Section 3 explores the IT research literature and examines the connection between IT, product development collaboration and mass customization. In section 4, we present our research design and findings, before concluding in section 5.

2. Mass customization strategies

Delivering what the customer wants at the right time, quality and price is a strategic imperative for many manufacturing firms. Automotive manufacturers have responded to an increasing demand for customized vehicles by mainly offering more product variety and feature options. However, this strategy does not equate to customization; in particular, if one considers that the majority of vehicles are sold from stock, and are not made to order (Holweg and Pil 2001, 2004). Customization beyond simply changing the exterior colour or adding an option requires a substantial development effort (or fundamental changes in manufacturing operations), which is generally prohibitive.[1] Consequently, automotive customization is often limited to certain late configuration at the dealer and by the aftermarket (Roemer 2003).

In this light, mass customization, which is often misrepresented and misinterpreted as a single concept, becomes more of a 'continuum of strategies' (Lampel and Mintzberg 1996). The applicability of these strategies is contingent upon the value chain configuration (cf. Duray *et al.* 2000, Silveira *et al.* 2001). In the automotive industry, customization approaches range from late configuration at the dealer, to modularization, strategic postponement in the production process, to complete customization involving bespoke component design (Holweg and Pil 2004).

Adapting existing customization frameworks (Lampel and Mintzberg 1996, Gilmore and Pine 1997), we define six basic customization strategies (figure 2) depending on the point of customization, which result in a continuum from offering standard products, to entirely customized vehicles.

2.1. *Customizing standard products*

In the first strategy, completely standardized products are offered. Customization is not achieved through varying product features, but through customizing the service associated with the product. This could be a free telematics system offered with the vehicle, for example.

The second strategy also revolves around standard products, which are configured, adjusted or altered to customer specifications. Configurable or adjustable products can be a direct substitute for mass customization. By designing products that can easily be adjusted to fit multiple sizes, tastes or functions, consumers can customize products on their own. An example of a configurable product is the adjustable car seat.[2] In addition to adding more flexibility to customers, it is also often more economical for OEMs to design adjustable products than to mass customize them.

Similar to adjustable products, customization with alterable products occurs by tearing down parts (or subsystems) of the product and replacing them with others, or by performing additional operations on the product. Examples include replacing components such as steering wheels or stereo systems with aftermarket parts, or adding body-kits to standard vehicles.

2.2. *Customized assembly and production*

The third strategy achieves customization through custom-assembly of standardized components, as in the classic case of Dell Computers (Fortune 1998). The crucial enabler of assemble-to-order production is

[1] These may include fitting high-performance engines into small cars, for example, which may require extra studies to ensure that the transmission subsystem will function with the engine; other vehicle dynamics need to be considered and adjusted accordingly.

[2] In the late 1990s, Toyota discussed offering their customers custom-made car seats. Toyota even set up a prototype of a seat-measurement device at its visitor centre in Toyota city. This concept never evolved further though; instead adjustable seats developed rapidly (Zipkin 2001).

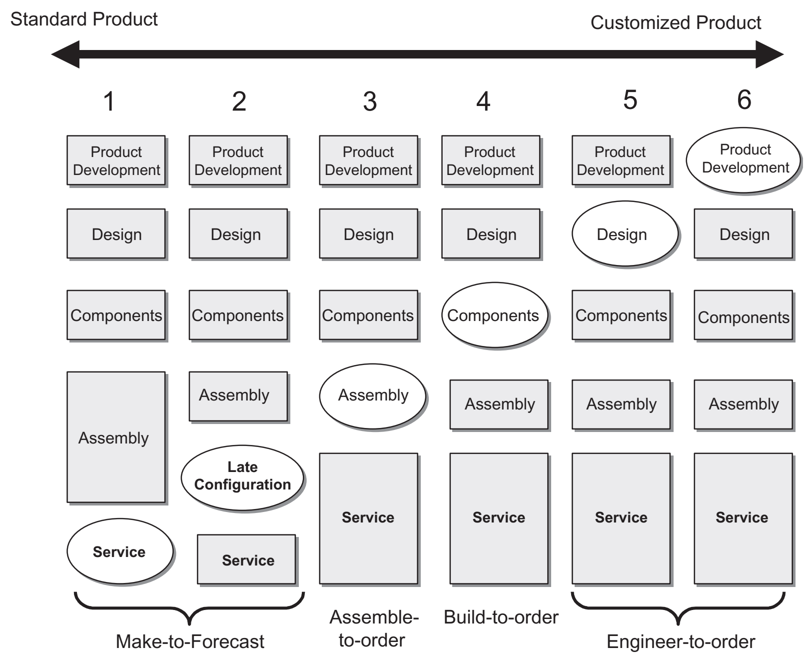

Figure 2. A spectrum of customization strategies (adapted from Lampel and Mintzberg 1996).

the interchangeability of components through standard interfaces, or 'modularity' (Starr 1965, Baldwin and Clark 1997).

Design modularization refers to the degree to which functions of a product are designed through independent modules that are connected together through standardized interfaces. Modular product architectures facilitate functional and organizational decoupling, and consequently enable mass customization. The key is in designing products that can easily be reconfigured to form variants, thus providing firms the flexibility to customize products quickly and inexpensively. Examples include HP copiers (Feitzinger and Lee 1997), Sony Walkmans (Sanderson and Uzumeri 1996), and the Smart Car, which is assembled from seven key modules rather than several hundred or thousand individual components.[3]

2.3. *Customized product design*

Customization to the point that an individual 'one-of-a-kind' product is offered, can only be achieved by going beyond standard products, components and product platforms. In addition to manufacturing and supply-chain capabilities, this also requires design and product development capabilities. We distinguish two forms here, 'customized design' and 'customized development', which are both subsumed into Mather's 'engineer-to-order' strategy (1988).

We define 'customized design' as the alteration of an existing set of components, based on a standard product platform, whereby the actual product platform maintains its physical characteristics. Examples include special vehicle orders, such as ambulances and police vehicles. While being based on standard structures, significant changes are made to accommodate the individual customer needs. Ambulances, for example, generally have a patient room customized to specific emergency medical service (EMS) requirements that incorporate as many features as the customer is willing to pay for. The chassis, however, remain largely interchangeable, and customers can choose between several front ends, supplied by the vehicle manufacturers. Mercedes-Benz, for example, will only provide a 'naked chassis' and the driver's cabin, whereas the patient compartment is built by specialists such as Binz in Germany or Horton in the US.

In the final strategy, 'customized development', all components are developed and designed to customer specifications. The key difference to customized design is that the design will not be changed to accommodate standard parts, but will only use existing components if they fit into the framework laid out by the customer's

[3] See www.smart.com for more information on the seven system partners, which are co-located on the Hambach factory site.

specifications. The classic example here is a Formula 1 racing car, which is custom-built each season according to the latest technological developments.

Overall, we see the point of customization shifting upstream in the value chain. By migrating upstream in the value chain, original equipment manufacturers (OEMs) can leverage customization much more extensively. This shift in the locus of customization (as depicted by figure 2) makes customization more the responsibility of the assembly plant, and to an increasing extent involves suppliers of key components. However, this migration requires increased intra- and inter-company communication and collaboration. This is where advances in IT become important. The capability of automotive firms to mass-produce customized products is tightly linked to their ability to communicate and collaborate with key suppliers on a timely basis. Thus, tools facilitating collaboration, and in particular information technologies, gain paramount importance. In the following, we will focus on the role of IT in the customization process.

3. The role and impact of IT in product design customization

3.1. *Information technology types*

In this section, we explore the different ways in which advances in IT can support the required channels for communication and collaboration between organizations and their suppliers. This tight synergistic integration results in the creation of competitive organizational networks capable of efficiently and economically delivering customized product designs (Joglekar and Yassine 2001).

To understand, map and evaluate the contribution of IT tools to various impact areas, we distinguish between four different types (of IT tools), depending on their functionality: (a) communication tools (b) visualization tools (c) calculation tools and (d) collaboration tools.[4]

Communication tools are typically used for sharing a variety of technical and business information for the purpose of conducting distributed transactions and/or to support globally dispersed development teams. These tools range from simple telephones and fax machines, to e-mails, video conferencing, shared databases and e-Business solutions.[5]

Visualization tools are important to display, share and communicate non-contextual information, such as product designs and engineering drawings. Three-dimensional CAD systems (such as CATIA, ProEngineer and IDEAS) are the most popular type of tools. With the advances of 3D-CAD technologies, 'digital mock-ups' are now replacing the need for building physical prototypes (or at least allow designers to inexpensively build many generations of digital mock-ups before building the final physical one). The ability to do so allows designers to test problems of interference between components and modules early on and correct them at low cost.[6]

Calculation tools refer to IT tools that allow the manipulation of data and the creation of new knowledge. Such tools consist mainly of simulation software and mathematical prototypes/models. These CAE tools have the potential to dramatically reduce product development time and cost. Evaluating design concepts in hours rather than months and exploring alternatives, which are hard, if not impossible, to prototype physically, reduce product development time. For example, building an automotive physical prototype usually takes between four and six months to construct, with an average cost of $500,000. Using CAE and CAD tools, an engineer could prepare the design model and simulate it in two to three days, for about $2,000 (Crabb 1998, Thomke 1998).

Many 'traditional' IT tools (e.g. CAD and simulation tools) can facilitate combining and brokering diverse and distributed capabilities within and across organizational boundaries. However, an emerging new breed of tools, called **collaborative product commerce** (CPC), is making its way into becoming the next major IT initiative. CPC enterprise solutions use the internet to create an online community for all development partners (including suppliers and customers) allowing them to collaborate in creating, developing and managing products throughout the entire product design and development process. CPC subsumes many smaller, previously isolated, markets that address various phases of product development, such as CAD/CAM/CAE, product data management (PDM) and project management.

3.2. *The impact of IT tools*

The first-order hypothesized impact of IT is the most direct, and the benefit comes from improving the

[4] This distinction is only one possibility, and other divisions have been proposed, for example, by Shapiro (2001) who divides them into *transactional* and *analytical*, or Thomke and Fujimoto (2000), who divide these technologies into *fit* and *function*.

[5] Duarte and Snyder (1999) used the 'term groupware' to describe the categories of electronic systems that integrate hardware and software to facilitate communication in dispersed teams.

[6] A decade ago, General Motors built 80 physical prototypes (at about $300,000 each) to validate and test designs for its 1991 Chevrolet Caprice. Today, GM builds about 20 prototypes for its cars and trucks, and it does most of other testing on computers (Brennan 2001).

efficiency of executing business transactions, performing individual tasks and streamlining information flows. The second-order IT impact manifests itself through facilitating collaboration and co-development within and across organizational boundaries. The last area provides the most abstract form of IT impact in terms of facilitating the creation and exchange of new knowledge among development partners. We elaborate on each of these impacts in turn.

3.2.1. *Information processing and exchange*

Firms are complex information processing networks (Clark and Fujimoto 1991). Information flowing within these networks empowers people to execute their tasks and coordinate with others. The impact of IT is determined by the degree to which IT tools change the time and cost of information processing and exchanging (Malone and Crowston 1994). The improved *efficiency* brought by IT systems is due to the following sources:

(a) **Faster information exchanges:** using IT communication capabilities result in faster and more reliable information access and release.
(b) **Faster execution of tasks:** using IT-based tools speeds up the execution/processing of individual tasks.
(c) **More concurrency and new dependency structures:** using IT to change the information structure of a process allows for more concurrency in executing tasks.

The first two points, above, are a direct result of either automating individual tasks or establishing an electronic linkage between collaborating entities, resulting in a faster process and allowing for smoother information flows. Engineering examples usually refer to the sometimes drastic improvements in development speed obtained from using CAD, CAM and simulation tools (Thomke 2001, Thilmany 2002). Business examples, on the other hand, usually cite savings in transactions costs due to using B2B and B2C systems (Lapidus 2000).

The third point, above, is more subtle to illustrate, as fewer such observations are cited in the literature. Aoshima *et al*. (1999), for example, found that the impact of introducing 3D-CAD into engineering organizations is not limited to changes in individual design tasks. Advanced 3D-CAD systems also change existing task boundaries for individual design tasks and the relationships between multiple design tasks. Process restructuring due to IT include the elimination of some old tasks, the addition of new tasks and the revision of some task dependencies (Yassine *et al*. 2000).

3.2.2. *Collaboration*

Collaboration requires a higher form of information processing and exchanging. IT tools, in this regard, allow blending and brokering of collaborative contributions throughout the network of design chain partners by facilitating 'rich' communication, instead of mere information exchanges. The evolution of B2B exchanges from initially brokering simple buy/sell transactions to offering value-added services by establishing 'platforms' for collaboration (i.e. covisint.com) is a case in point. This evolution represents the shift from supply-chain management, i.e. information sharing, to design-chain management, i.e. collaboration.

As an example, the DOME project at MIT (Wallace *et al*. 2000) creates a product development 'marketplace' that uses the internet to allow engineering, marketing, manufacturing, accounting, suppliers and customers to make critical pieces of their knowledge and expertise (i.e. 'services') instantly available (via 'publishing') to the rest of the development community in an integrated, uniform and simple interface. DOME integrates all the different pieces of information together. For example, a chassis designer may simulate the performance of a supplier's shock absorber by simply downloading its data model from the supplier's website and plugging it into the local chassis data model. Furthermore, the tool allows the chassis designer to share the results of the simulation with the shock absorber supplier online, resulting in efficient design improvement cycles. Finally, changes in chassis design are readily translated/linked into the shock absorber model to instantly assess and propagate the impact of design changes within the design chain.

The impact of IT is determined by the degree to which these tools change the time and cost of collaboration mainly due to the following sources: defining standard links and interfaces between development participants, managed and structured information exchanges allowing participants to work in parallel, and integrating shared processes among supply-chain partners in order to achieve responsive and robust supply-chain operations (Kisiel 2001).

3.2.3. *Knowledge creation and sharing*

Competition in the automotive industry is transformed into a competition between groups of related companies rather than between individual companies (Dyer and Nobeoka 2000). Under this competitive structure, organizations form competitive networks using strong communication and information linkages.

The goal of these information linkages is to create, aggregate and exchange knowledge within and across organizations. Knowledge sharing and creation are the main competitive advantage of such networks, as it speeds the pace of innovation in organization, especially if this creation process is established across organizational boundaries.

According to Nonaka (1994), knowledge is considered to exist in two forms: explicit and tacit. Explicit knowledge is recorded in formal syntax. Once codified, it can be readily stored and communicated, such as the designs stored in CAD files. Tacit knowledge, however, exists as the result of personal experience and memory such as the judgement that makes an engineer choose one design over another. It requires context in order to be explained and communicated. In order for knowledge creation to be effective, four modes of information transfer must exist: socialization, internalization, externalization and combination (Nonaka 1994).

Advances in information technologies influence knowledge creation and sharing processes in many subtle ways (Raven 1999). No single communication process or tool accommodates all forms of knowledge transfer (Nonaka *et al.* 1996). Different strategies and information technology tools are required to achieve different modes of communication necessary for knowledge creation. For example, B2B systems allow for communicating explicit information between OEMs and their suppliers, but are insufficient for delivering more tacit information required to mutually develop a new product. The key is to understand how IT tools help implement knowledge creation and sharing.

Since socialization involves tacit-to-tacit knowledge transfers, face-to-face meetings are more effective than any IT tool available. However, as organizations go global and virtual, face-to-face meetings are often not possible or prohibitively expensive, but socialization can still be facilitated with IT tools such as video/virtual conferences, chat rooms and electronic blackboards. Externalization involves the conversion/exchange of tacit-to-explicit knowledge. IT tools such as electronic blackboards etc. can be used for externalization. Furthermore, CAD systems can play a central role in the creation of knowledge (Baba and Nobeoka 1998). Shared databases allow for knowledge creation by facilitating interactions among designers and engineers and by improving the degree of their collaboration. For example, sharing design ideas with other designers enables designers to confirm a design from a variety of different viewpoints and resolve design conflicts. IT tools influence knowledge creation through 3D full visualization, simulation of complex processes and better communication/coordination.

3.3. *Conceptual framework*

As noted earlier, by migrating up the value chain OEMs can leverage customization more extensively, but this requires increased collaboration with key suppliers. We have further argued that IT infrastructure and tools play a critical role in realizing such collaboration. In this section, we integrate these arguments into the conceptual framework shown in figure 3. This framework suggests that the level of collaboration (i.e. co-engineering), and thus customization, is dependent on a set of enabling IT technologies. The deployment of IT tools influences the efficiency of business and engineering transactions. IT tools also influence the richness of information sharing within and across organizational boundaries. Moreover, these tools can enable knowledge creation and sharing. While the level of information sharing determines the extent to which the extended supply-and-design chains are well managed and coordinated, knowledge creation and sharing determine the responsiveness of the customized development process.

Based on this conceptual model (figure 3), we constructed several hypotheses regarding the impact of IT tools and their contribution in support of design customization. First, we hypothesize the relationship between IT tools, through information processing and exchange, on enabling work coordination. Furthermore, coordination is hypothesized to influence information sharing and knowledge creation. Information sharing, coordination and knowledge creation are also hypothesized to impact PD capability. Finally, we investigate the relationship between information integration and PD capability on the customization capability. Specifically, the research

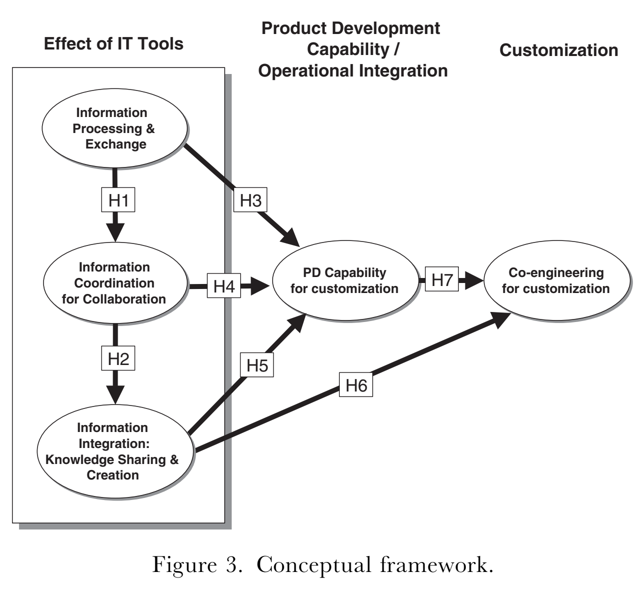

Figure 3. Conceptual framework.

hypotheses investigated are as follows:

- **Hypothesis 1:** a higher level of information exchanges enables more coordination.
- **Hypothesis 2:** a higher level of coordination enables more information integration for knowledge sharing and creation.
- **Hypothesis 3:** a higher level of information exchanges enables product development capability.
- **Hypothesis 4:** a higher level of coordination enables product development capability.
- **Hypothesis 5:** increased information integration enables product development capability.
- **Hypothesis 6:** increased information integration enables co-engineering for customization.
- **Hypothesis 7:** improved product development capability enables co-engineering for customization.

4. Empirical study

4.1. *Previous contributions: an overview*

Several empirical studies have been conducted with research focus on product development, customization and/or communication (Raven 1999, Holweg and Greenwood 2001, Novak and Eppinger 2001, Thomke 2001, Sosa *et al*. 2002). However, most of these studies either lack the IT research component, or had a much narrower IT focus, which is the main component in our study. Thomke (1998, 2001), for example, focused on the impact of simulation and CAD tools on PD performance, whereas we take a more holistic approach to IT by considering a larger pool of IT tools including collaboration and knowledge creation tools. Raven (1999), on the other hand, studied how IT facilitates knowledge creation and sharing in product development teams. Sosa *et al*. (2002) used empirical evidence from the telecommunications industry to test hypotheses about the use patterns of electronic communication media by distributed product development teams. Finally, co-testing of design complexity and supply-chain performance has been considered using auto-industry data (Novak and Eppinger 2001), but no explicit questions have been asked about IT's role in design performance, or how this role will be influenced by supply-and-design chain structure.

4.2. *Research setting*

The data for testing the hypotheses were collected from Korean automobile first-tier suppliers. Due to the single industry setting, generalization of findings is expected to be limited; however, internal validity is expected to be high (Judd *et al*. 1991).

For this research, a structured undisguised survey questionnaire was developed to collect data on supplier attitudes towards the connection between IT tools and design customization. For the quantification of the relevant constructs and relationships that are built upon the conceptual model (i.e. figure 3), the survey technique required a standardized instrument. The survey design was thus specifically laid out to allow for the application of a linear structural relationships (LISREL) analysis of the responses (Joreskog and Sorbom 1993).

The survey contained 10 modules, with a total of 130 questions. In the first section we asked 10 general (i.e. background) questions about the company, its primary product (or product family), its major customer and main suppliers. The next section concentrated on asset specificity (a total of six questions). Section III contained a sequence of 23 questions characterizing the customization aspects of the product as outlined in section 2 of this paper. Section IV characterized the nature and intensity of information exchanges that take place between the company, its main customer and supplier (a total of 10 questions). The largest part of the survey is Section V, which comprised 47 IT benchmark questions. These questions covered the whole spectrum of IT tools from simple internet usage and e-mail tools to supply-chain management, to sophisticated simulation, visualization and collaboration information technologies. Section VI had 12 further questions evaluating respondents' opinions regarding the effects of IT in their company. Section VII had eight questions assessing the amount of information sharing and creation in the company. Sections VIII, IX and X contained questions relating to the degree of involvement that the company has with its main customer, productivity-related questions and barriers to using IT, respectively. Except for the first two sections, all questions in the survey were assigned a seven-point Likert scale.

4.3. *Sample design*

The survey questionnaires were sent by mail between June and August 2002. In order to ensure satisfactory response rates, respondents were contacted one month after the initial questionnaire administration. A total of 450 survey questionnaires were sent out to Korean automotive first-tier suppliers (a survey was administered to each first-tier supplier of the four major car makers in Korea: Hyundai-Kia, GM-Daewoo, Ssang-Yong and Renault-Samsung). From a total of 182 responses received, five were classified as inadequate due to incomplete answers or void responses. The remaining 177 responses were used for the analysis. The descriptive characteristics of the valid 177 samples are shown in tables 1, 2 and 3. Overall, the spread by OEM customers mirrors the production volumes by these manufacturers, and thus eliminates any concerns regarding a bias towards a certain vehicle manufacturer, or even a single production site.

Table 2 further outlines the number of major customers by supplier – as can be seen, the large majority of suppliers are dedicated to, or have, one main customer. In our view, this is a critical prerequisite to developing in-depth and collaborative relationships with the customer, since a multi-customer supplier will face concerns with regards to loyalty and confidentiality.

Finally, table 3 outlines the products supplied by the companies surveyed. Again, the spread of components is important to avoid any bias towards a certain component cluster or production technology or process (i.e. metal pressing or plastic moulding).

Table 1. Sample size by OEM customer.

Major OEM	No. of companies	Per cent
Hyundai-Kia	86	48.6
GM-Daewoo	55	31.1
Ssang-Yong	15	8.5
Renault-Samsung	21	11.9
Total	177	100

Table 2. Percentage of suppliers' sales to major OEM.

Sales ratio of major OEM	No. of companies	Per cent
0-20	28	15.8
21-40	13	7.3
41-60	19	10.7
61-80	17	9.6
81-100	100	56.4
Total	177	100

Table 3. Categories of suppliers by product type.

Component	No. of companies	Per cent
Power train	41	24
Steering, brake, suspension	11	6
Body and sash	33	19
Battery and parts	1	1
Electric parts and wiring	27	16
Interior	26	15
Wheel, tyre	8	5
Other	24	14
Total	171	100
Not applicable	6	

4.4. *Operational variables*

In our analysis we used three independent variables (information processing, information coordination and information integration) and two dependent variables (PD capability and co-engineering). These variables directly relate to the conceptual framework presented in subsection 3.3. To actually measure these variables, both independent and dependent, we defined one or more measurement variables. These measurement variables relate to indices of the answers in the respective parts of the survey.

The operational variables for the three constructs – i.e. 'information processing', 'information coordination' and 'information integration'– of the model in figure 3 were developed based on previous studies by Kim and Im (2002). They show that the reliability of the operational variables can be satisfactorily tested by Cronbach's alpha (α) coefficients. The operational variables for the two other constructs – i.e. 'product development capability for customization' and 'co-engineering for customization'– were developed after in-depth interviews with industry experts.

Figure 4 outlines the measurement variables (boxes) that relate to the respective operational variables (circles). For example, information processing/exchange is defined through three sub-variables, namely the indices for information exchange through IT systems of sales-related inventory-related and new product development-related information. These indices in turn have been derived from the answers of the respective set of individual questions, all of which are measured on the same Likert scale.

4.5. *Empirical results*

Structural equation modelling using conventional maximum likelihood estimation techniques (Joreskog and Sorbom 1993) was utilized to determine the general fit of the model and the data, as well to test the individual hypotheses. A structural equation model (SEM) was established based on the conceptual model proposed. Figure 4 shows the LISREL outputs in a path diagram, including all the latent variables and indicators as used in the calculation with the AMOS 4.0 software from SPSS Inc.

The following test statistics of model and data fit were calculated: the chi-square was 77.772 with 59 degrees of freedom, and a significant p-value at 5% level. The other fit indices further confirmed that the data were fitting into the conceptualized model: both goodness of fit (GFI) and normed fit indices (NFI) are greater than 0.9, and the comparative fit index (CFI) shows 0.985.

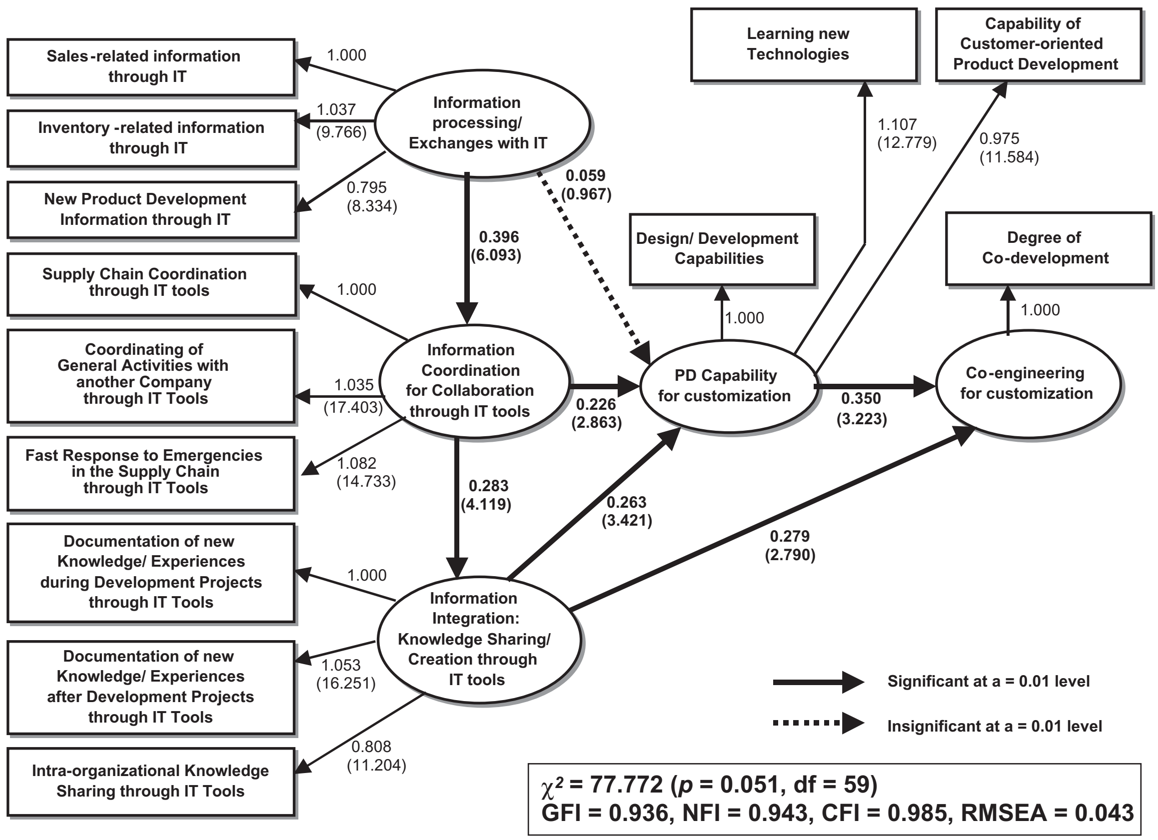

Figure 4. Summary of test results: LISREL output.

Table 4. Summary of test results.

Hypothesis	Causal relationship between variables		Standardized coefficient	*t*-value	Acceptance
1	Information processing/ exchange	Information coordination for collaboration	0.396	6.093	Yes
2	Information coordination for collaboration	Information integration for knowledge sharing/creation	0.283	4.119	Yes
3	Information processing/ exchange	Product development capability	0.059	**0.967**	**No**
4	Information coordination for collaboration	Product development capability	0.226	2.863	Yes
5	Information integration for knowledge sharing/creation	Product development capability	0.263	3.421	Yes
6	Information integration for knowledge sharing/creation	Co-engineering for customization	0.279	2.790	Yes
7	Product development capability for customization	Co-engineering for customization	0.350	3.223	Yes

Finally, the root mean square error of approximation (RMSEA) is less than 0.05, showing a value of 0.043. Therefore, the overall fit of the model was found to be in more than acceptable boundaries.

The LISREL analysis results are also summarized in table 4. Six paths among the tested seven hypotheses were found to be significant, with *t*-values >2.00 and considering the number of cases analysed. As shown in the table, most LISREL coefficients are significant at the $\alpha = 0.01$ level except for the link information processing/ exchange – information coordination for collaboration, which shows a non-significant *t*-value of 0.967. Interestingly, information processing/exchange showed a positive causal effect on information coordination for collaboration, while it showed an insignificant causal effect on the PD capability for customization.

5. Discussion and conclusion

Mass customization spans a wide spectrum of strategies ranging from 'design customization' to point-of-sales configuration and aftermarket alterations. In many industries, but in the automotive industry in particular, customization efforts are mainly located at the downstream side, namely at or after the point of sales, thus limiting the opportunities of customization. However, migrating up the value chain towards design customization has its challenges as it involves a widening network of suppliers, manufacturers, distributors, technology providers and retailers. For design customization to be 'practical' and economically viable, close collaboration of these value-adding participants is required. Information technology can provide the means to make these partners work in concert with each other to produce customized goods efficiently through a three-tiered transformation: efficiency, collaboration and knowledge sharing and creation.

Our main research goal in this paper was to understand this transformation by proposing and testing a conceptual model of how IT can facilitate such a transformation. Consequently, this model laid the groundwork for the development of a survey to empirically examine the role and impact of IT in achieving customization in the automotive industry. Data from Korean automotive first-tier suppliers on their attitudes towards the connection between IT tools and design customization were gathered and analysed. The results of the study can be summarized in the following managerial suggestions and guidelines:

(a) Firms pursuing design customization should not limit their IT investments to communication and transactional tools, but instead emphasize investments in technologies that enable collaboration and knowledge sharing within and across organizational boundaries.
(b) Product development (PD) capability does not improve by mere exchange of explicit information. However, this type of IT connectivity is a requirement for enabling collaboration, which in turn facilitates knowledge sharing and creation.
(c) Investment in information technologies that allow for knowledge sharing and collaboration results in improved PD capability, which in turn facilitates design customization. Investment in IT that only creates information visibility in the supply chain, however, does not.
(d) Overall, a balanced IT strategy that has the organizational support framework to use this capability for inter-organizational collaboration and knowledge sharing is a strong factor for improving a firm's PD capability in support of higher levels of design customization.

These results do not only support our initial qualitative analysis, presented in earlier sections of this paper, but also agree with previous IT studies conducted by Thomke (1998, 2001) and Raven (1999) regarding the positive role of IT in improving PD capability and knowledge sharing/creation. Moreover, the efficiency effect of IT is also well documented (Brynjolfsson *et al.* 1994, Thomke 2001), but the higher-level impact on collaboration, knowledge creation, and ultimately design customization is somewhat recognized but not yet documented (Sethi *et al.* 2003).

While the overall results of IT's enabling function in design customization is not too surprising, the missing link between 'information processing/exchange' and 'PD capability' is. One would expect that the mere visibility of data in the system would facilitate better customization capabilities, since the availability of appropriate information is an obvious key enabler of customization. Thus, the main conclusion we reached in this analysis is that we need to take a more differentiated view of information technology. Providing inter-organizational visibility of data throughout the design chain (through elaborate technology) is in itself not an enabler of improved collaboration in general, and design customization capability in this particular case. Establishing an IT infrastructure is a necessary condition, but if product customization is the goal, it is bound to be futile unless the organizational structure is capable of employing this newly available data.

Nevertheless, the second main conclusion of our analysis is that IT indeed facilitates customization, and that IT will play an increasing role in customizing products in the future. In design customization, the organizational boundaries and roles of the various players in a design chain will fade out. Organizations in the design-and-supply chain need to work together more closely, and their activities need to be coordinated more tightly. Creating and sharing knowledge with development partners will become increasingly important, as design chains became the unit of competition in this business environment.

Few limitations (and possible extensions) of our research should also be addressed. IT's direct and higher-level impacts cannot function outside of what institutional arrangements allow, such as organizational and inter-organizational decision rights and incentive issues (Yang 2000). Our analysis in this paper ignored such organizational variables in assessing the impact of

IT on design customization, yet guides management to look for the appropriate institutional arrangements to enable IT's design efficiency and collaboration effects.

Finally, the results represent a very comprehensive coverage of the Korean first-tier component supplier industry, which provides a high reliability of the internal validity of the study (also reflected in the statistical testing for the fit of model and data). Nevertheless, the study is obviously geographically limited. Hence, future steps in our analysis will be to increase the geographical coverage by replicating the survey in other main automotive production regions, namely Europe, North America and Japan. Such a global study can also serve as a basis for a comparative study detecting differences in IT usage for enabling design customization.

Acknowledgements

This research was generously supported by the Center for eBusiness at MIT.

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