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Application support to product variety management

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Offering a large variety of products at competitive prices and reasonable delivery times is a complex managerial challenge that many companies have to address. Software vendors responded to this challenge by developing and proposing various solutions, such as product configuration (PC) systems, product data management (PDM) systems and customer relationship management (CRM) systems. The relative newness, complexity and mutual interdependencies among these systems make it difficult to understand how they—individually and as a whole—actually support a firm in managing its product variety. Precisely these complexities, ultimately, add to the risks of software selection, leading companies to make inconsistent choices or to implement the wrong systems. Starting from this theoretical and practical concern, the present paper provides a conceptualization of the essential functions of PC, PDM and CRM systems, discussing how these functions help a company to manage its product variety and how they relate to each other. This paper proposes that two core data structures of PC systems—namely the sales and technical configuration models—are essential elements of the information management infrastructure of a company offering a large variety of products, because they enable a number of important product variety management functions also present within PDM and CRM systems.

Keywords: Product variety management; Mass customization; Product configuration; Product data management; Customer relationship management

1. Introduction

Competitive dynamics nowadays forces many manufacturing companies to offer multiple product varieties to their customers, while keeping prices and delivery times competitive (Cox and Alm 1998, Funke and Rudwel 2001). This represents a difficult challenge, as product variety negatively effects business process efficiency and effectiveness, resulting in potentially severe disruptions of cost and time performances (Sackett and Bryan 1998, Åhlstrom and Westbrook 1999, Zipkin 2001, Salvador and Forza 2004a, Steger-Jensen and Svensson 2004). Hence, those companies which can deliver to their customer the right variety at lower prices, more rapidly and with better quality will enjoy an important market advantage

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over less efficient and less effective competitors. The issue, then, is to reduce the trade-off between product variety and operational performances.

The possible approaches that have been proposed to 'manage for product variety' (e.g. components standardization postponement, product platform design, etc.) pose demanding requirements in terms of information processing, storage and retrieval. This can be explained by recalling that product variety results in increased task uncertainty for an organization. Since task uncertainty implies a mismatch between the information processing capability of the organization and the information processing requirements placed by the environment (Galbraith 1974), evidently the fit between the organization and its external environment can be improved by augmenting the information processing capability of the organization (see Pine *et al.* 1993, Kotha 1995). For example, a product configuration system reduces the salesperson's uncertainty when dealing with a customer, as it reduces the need for the salesman to look for missing pieces of technical product information held by different individuals across the organization.

Software vendors reacted to the product variety management problem by adding to their product lines a whole array of IT solutions that provide an information processing support to the management of product variety. Sometimes, supporting the management of product variety is the very goal of these IT solutions, as in the case of product configuration (PC) systems. In other cases, even though these IT solutions are particularly useful for product variety management purposes, they serve broader goals, as in the case of product data management (PDM) systems and customer relationship management (CRM) systems (Steger-Jensen and Svensson 2004).

Understanding how these IT solutions support product variety management is a complex conceptual task, one that makes software selection particularly risky and uncertain. Of course, this fact may be plausibly related to the continuous evolution these systems are undergoing. The absence of a dominant architecture (see Utterback and Abernaty 1975), in fact, makes it difficult to synthesize and compare the features of these systems. Software vendors, in this regard, are of no help, as they are not interested in making the assessment of the fit between customer information processing needs and the information processing features of their products easy or clear.

The present paper aims at clarifying the contribution of PC, PDM and CRM systems to product variety management, by analysing how the functions performed by these systems help in reducing the trade-off between product variety and operational performances. We pursue this objective by synthesising the key functionalities of PC, PDM and CRM systems, as well as by showing how these functionalities—individually and as a whole—support product variety management. In discussing the implications of our research, we show how PC systems play a central role in the definition of the information management architecture of a company pursuing high product variety strategy.

From a methodological standpoint, in this paper we will not reference any specific IT-based system available in the market, since our aim is not to compare the capabilities of different commercial products. While one may argue such a high-level of analysis can yield only basic insights, we are not aware of other integrative models attempting this kind of comparison. Furthermore, a high-level analysis would, plausibly, lay the foundations for more detailed

analyses that can be applied to compare commercial applications. Based on our experience in industry we have, in fact, witnessed countless cases of companies selecting the wrong type of information system because of an inaccurate understanding of system functions. In this light, a simple categorization has the undisputable advantage of being easily assimilated by the decision maker, avoiding at least macroscopic errors.

2. Product configuration systems

Product configuration systems (also called configurators) support the configuration process, defined as the set of activities from the collection of information about customer needs to the release of the product documentation necessary to produce the requested product variant (Forza and Salvador 2002, Forza and Salvador 2006). This process can be subdivided in two sub-processes namely the sales configuration process and the technical configuration process (see figure 1).

The sales configuration process includes all the activities carried out to identify the complete and congruent commercial description of the product that best fits customer requirements. The customer's needs are the input of the configuration process. A pre-requisite of an adequate translation of these needs into product characteristics is the appropriate communication of the possible solutions offered by the company, allowing the customer to explore the variety offered and helping him to find the product variant with the characteristics that best suit his requirements. During the sales configuration process, when the sales characteristics to be defined are dozens or maybe hundreds, a technical support for sales configuration activities becomes necessary. The sales configuration process ends with the definition of the sales configuration. The sales configuration represents the description of the product the customer is willing to buy and the company agrees to supply. In the sales description of the product some characteristics not strictly associated with the product itself, from the material point of view, can be included, such as price, delivery terms, packaging, etc.

The technical configuration process includes all the activities that generate the documentation of the product variant, based on the sales description of such variant. The technical configuration process takes as an input the sales configuration chosen by the client, and then identifies the product components corresponding to these

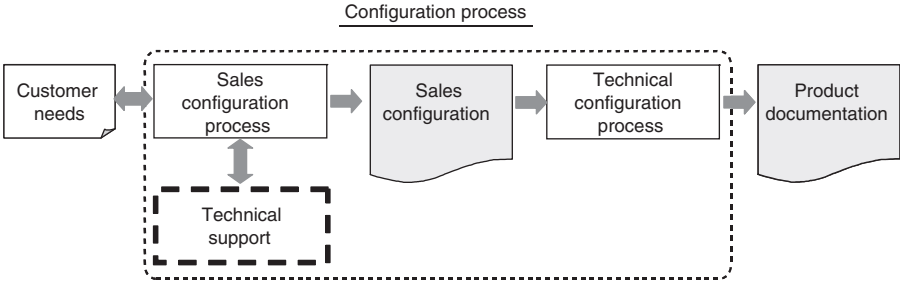

Figure 1. A generic product configuration process.

characteristics as well as the process steps needed to make and join these product components. The output of the technical configuration process may be stored and formatted according to predetermined logic structures such as production sequences, bills of materials, drawings, etc.

2.1 *Configurable products*

Configuring a product, rather than designing it, implies that no component design activities are needed to define the required product variants (Salvador and Forza 2004a). To offer configurable products a company should comply with two requirements. The first requirement is a precise definition of what the company is potentially ready to offer and what it is not ready to offer. In other words, the company limits a 'product space' within which the customer will try to satisfy his specific needs. The second requirement demands the necessity to establish a link between the commercial characteristics of the product and the technical characteristics. The products variants are somehow pre-designed, and their feasibility has been evaluated when defining the family product. In this way it is possible to reduce uncertainties linked to production operations in the configuration process. This simplification, in principle, should benefit efficiency and responsiveness of companies that offer product variety.

In practice, product configuration per se offers limited support to the management of product variety. This is widely documented in the literature exploring the problems faced by those companies that adopt the product configuration approach to variant generation (Sviokla 1990, Forza and Salvador 2002a, Forza and Salvador 2002b, Tiihonen *et al.* 1995). In the sales configuration process the main issues regard the difficulties of salesmen in managing product alternatives, ensuring technical feasibility, having the necessary product information, in pricing the product, and in determining the product delivery date (Forza and Salvador 2004). The consequences are long times and low precision in tendering, errors in the resulting sales configurations and a heavy involvement of the technical office in the tendering process. In the technical configuration process there is a significant amount of technical office human resources absorbed in drafting and checking technical product documentation (BOMs, routings, production sequences, etc) and in preparing product user documentation. The combination of the presence of repetitive, sometimes unnecessary, activities and errors in sales configurations lead to configuration errors in production orders and incorrect BOMS. The final results are long lead times and low efficiency in technical offices and in production.

2.2 *Product configurators functions*

Product configurators are a class of applications intended to make the product configuration process faster and more reliable thus overcoming the above mentioned problems. The configuration process shown in figure 1 maintains its validity both in the case in which the configuration activities are carried out 'manually' and in the case they are supported by a PC system. If a PC system is used, the necessary knowledge must be formalized (Felfernig *et al.* 2001) using suitable

logic structures, namely the sales configuration model and the technical configuration model.

Sales configuration. The sales configuration model is a formal representation of the product space and of the procedures according to which a sales configuration can be defined within such space. The sales configuration model includes sequences of questions which make it possible to progressively define all product characteristics. These questions guide the client or the sales agent towards the definition of a set of product specifications that are as close as possible to the client's needs, thanks to the fact that these questions are expressed in the language used by the client to describe the product. At the same time, it is possible to verify the compatibility of these specifications, making sure that the client does not express constrasting requirements or requests non-existing features. Finally, these logic structures make it possible to ensure that no specifications are missing, which would make further contact with the client necessary and cause possible product configuration variations, above all in the case of complex products with a great deal of client specifications.

Technical configuration. The technical configuration model, also called product model, is a formal representation of the links between the commercial characteristics of a product and the documents that describe each product variant (bills of materials, production and assembly cycles, etc.). The product model, therefore, is a logical structure that formally ties what product characteristics are offered to how products are actually made. The technical configuration models include the information and the rules to produce all the BOMs of the product variants of the product family. Modern configuration systems include sales configuration modellers and technical configuration modellers, which are programs that support the creation and modification of the sales configuration model and the technical configuration model without the need for specialized programmers.

The sales model and the technical model are interpreted by ad-hoc programs known as configuration engines. The sales configuration engine reads the data stored in the sales model and interacts with the user in the sales configuration process. Similarly, the technical configuration engine reads the data stored in the technical configuration model and automatically produces the product documentation required before putting the product into production.

In synthesis, a product configurator makes it possible (Forza and Salvador 2002a, Steger-Jensen and Svensson 2004) to:

1. Guide the user in generating or searching for complete and valid product configurations (i.e. product variants).
2. Supply information in real time on the feasibility of a product configuration, on the prices, or on the technical characteristics of components and products.
3. Generate sales offers.
4. Generate the data sequences (configuration) that are necessary for obtaining the order, create an article code for product identification or the automatic generation of bill of materials, production sequences, production drawings etc.

In addition, by means of the modellers, a product configurator also permits one to:

1. Build a sales configuration model and, therefore, define the structure of the questions, constraints, phrases, images and films explicitly used during the sale.
2. Build or modify a product model, defining the product characteristics, the constraints that specify the relationship between the characteristics and the values that these characteristics can assume.

2.3 *Product configurators support to product variety management*

The advantages associated with using a software configuration system are numerous and concern both order acquisition and order fulfilment processes (Forza and Salvador 2002a, Forza and Salvador 2002b, Hvam 1998).

Order acquisition process. As for order acquisition, the use of a product configurator obviously makes it possible to simplify the handling of a large number of variants and reduce the sales configuration errors. The system also fills sales personnel's possible lack of technical knowledge—a serious problem when custom products are offered—thus reducing the number of designer interventions during the sales negotiation. In general terms, the consequence of all this is a reduction in the order acquisition process times and costs, as well as a reduction (which may arise from configuration errors) in the subsequent production activity costs. Finally, the incorporation of a whole series of feasibility checks inside the sales dialogue reduces the time, and therefore the cost, of sales personnel training.

Order fulfilment process. In the order fulfilment process, a product configurator helps the technical department to efficiently generate product variants in at least two ways. First, technical personnel no longer have to support salespeople. The automation of product documentation activities further magnifies this benefit, increasing the time available for more value-adding activities, such as new product development. Furthermore, the adoption of a product configurator prompts designers to reflect on the architecture of the company's product families and on the possible need to rationalize it. This is because more rational product architecture would ease the task of building a technical product model, a prerequisite for the implementation of a product configurator.

3. Product data management systems and product configuration systems

The configurator is fed with product data and elaborates product data, in the form of bills of materials, production cycles, drawings, etc. However, the goal of managing product information in an integrated way is pursued by the so-called product data management (PDM) systems (Peltonen *et al.* 1996).

3.1 *PDM functions*

PDM systems manage the integration, storage, retrieval, distribution and updating of product documents created mainly by the technical office, such as designs, BOM, cycles, manuals, numerical simulations, etc. More specifically, they implement three major functions (Peltonen *et al*. 1996, Philpotts 1996, Leong *et al*. 2002, Sackett and Bryan 1998, Hameri 1998, Miller 1998, Liu and Xu 2001, Kumar and Midha 2004):

- The organized and classified storage and distribution of product documents for easy retrieval during all product life cycle.
- The management of document status (draft, approved, phased out, etc), and the 'assembly' of complex sets of documents.
- The control and coordination of activities performed on product documentation by people belonging to different functions, groups, organizations, etc.

In the first place, PDM systems typically store data in an 'electronic vault' to make it promptly available to users (Philpotts 1996, Leong *et al*. 2002). The organized and classified storage of information in this 'electronic vault' reduces complexity in accessing product information, thus cutting non value-added time dedicated to search, recreation or distribution of product information. For example, a designer may need a certain component. Instead of designing it, he may use the PDM system to identify a functionally and morphologically similar one, across the already designed components. This functionality consents to re-utilize the existing components, to standardize them and to reduce the design activities needed to develop a new product (Peltonen *et al*. 1996, Weber and Werner 2003). The benefits of structured information acquisition and storing extend outside the engineering area, to include other functions, suppliers, consultants, customers, and other business entities that need to access and use company product data. This easier access to product information ultimately helps cutting product development cycle time.

Secondly, the system allows for managing document status, by clearly marking the condition of any given document across its life cycle; for example, distinguishing among 'draft', 'approved' and 'phased out' documents. Additionally, PDM systems can control who (people or departments) has the right to access, change or release any given product document. Finally, PDM systems allow the assembly of sets of related drawings, tenders, spreadsheets, etc, into complex 'meta-documents', that, for example, belong to a single project.

Lastly, PDM systems support the control of progress in document making, and so they allow project managers to manage new product development projects more effectively. This function becomes particularly critical when complex projects are being run. For example, once a designer has completed the design of a component, he can release it in the 'electronic vault' with the appropriate 'draft' status, At this point, the PDM system notifies the project manager of the completion of the event and asks for approval, without having the project manager continuously checking the progress status of each work package.

3.2 *How PDM functions contribute to product variety management*

PDM systems offer a number of opportunities to efficiently and effectively customize products, through all their three main functions.

Organized and classified storage and distribution of product documents. Product variety and customization bring uncertainty into the task of defining a standard for classifying and codifying product data, uncertainty that may ultimately result in inconsistent organization of product data. For example, different designers, while generating new product variants, may place functional groups or sub-assemblies in different levels or parts of the bill of material. This would make maintenance of bills of materials unduly complex and cumbersome. The PDM system may set certain rules that guide/force different designers across time to be consistent in the creation of product documents.

Management of document status and the 'assembly' of complex sets of documents. Product variety and customization multiply product documentation workload, as more documents have to be created, retrieved or modified. If a component is to be changed, it should be changed consistently across all product variants. PDM systems support this activity because they make it easier to identify all the relevant product documents and to systematically update these documents, a task that can be overwhelming when thousands of products variants have to be maintained or created. For example, when a product accessory has to be changed, the PDM system allows to retrieve drawings, bills of materials, part descriptions, part cost data and e-catalogue information, etc. that have to be systematically revised and updated. When a company has to comply with ISO 9000 standards, a thorough and reliable revision is mandatory and, in the absence of an appropriate PDM system, this may become extremely costly and time-consuming.

Control and coordination of activities performed on product documentation by different actors. Product variety and customization make the control and coordination of activities needed to bring about the development of new products more complex. This complexity partly arises from the time pressure associated with the delivery of a custom solution. Undoubtedly, automation of information transfer ensured by workflow functions would help a company to cope with the customization-related time pressure. Furthermore, to ensure efficiency in customization it is necessary that synergies and economies of scope must be preserved in the process of creating new products. For example, when an engineer is deciding what components are needed for a new product variant, the PDM system may constrain its choices to a previously approved component set. In the case that no item within such a set meets customer requirements, the PDM system may give the designer the option of issuing an authorization request for a new part, which would be immediately routed to the authorized decision makers (Peltonen *et al*. 1996).

3.3 *PDM and PC systems for product variety management*

The requirements placed by product customization upon PDM may become extremely demanding. PC systems offer a number of functionalities that, naturally overlapping with PDM functionalities, support the execution of certain customization-related tasks. Consequently, some customization-related tasks could be moved from the PDM to the PC system, thus keeping design and management of PDM system not too complex. The modalities through which PC features contribute to perform each one of the three PDM functions are synthesized and explained hereafter.

Creation of variant-specific documents. First of all, a number of product variant-specific documents may be created by a PC, rather than by the PDM system. This is especially true for those documents which release is triggered by order acquisition and fulfilment, such as bills of materials, CNC programs, operational sequences, etc. Of course, the creation of these documents, like any other product document, falls under the umbrella of PDM. However, since the PC supports order acquisition and fulfilment, it may generate product variant-specific documents as well.

Classification and coding of variant-specific information. PC and PDM functions also overlap when it comes to classifying and codifying product variant-specific information. Every time a product configuration is created, in fact, the PC system typically generates a part number and other indexing information that may be used for achieving and retrieving product variant-specific information—a fundamental function of the PDM system. PC systems can have even greater coding capabilities. For example, in cases where the product model includes coding rules, the PC can also generate new component codes and, if needed other component variant-related documents, such as drilling patterns, operational sequences, etc. (Forza and Salvador 2002b).

Workflow management in the product configuration process. Finally, PC and PDM functions overlap also when it comes to coordinating the activities related to the creation of a new product configuration. A number of PC systems, *de facto*, replicate some of the workflow management functions of PDM systems in the context of the order acquisition and fulfilment process. For example, when technical products such as power transformers are customised, a PC can guide the sales personnel into the task of specifying the product, through the interface of the sales dialogue. Likewise, the PC system can also guide engineers into the task of defining product features that are not automatically defined, through a later technical dialogue (see Forza and Salvador 2002). As such, the PC is shaping and controlling the flow of customization-related activities within the order acquisition and fulfilment process, assigning task to people and groups, as well as defining the sequence according to which these tasks have to be carried out.

Even though PC and PDM systems share three high-level product variety management functions, they cannot be considered as alternative IT solutions.

In fact, they differ in a number of peculiar functions, consistent with the fact that they are conceived to serve different purposes. PDM systems are for managing, engineering product data, while configurators are meant to gear sales, engineering and production activities in the acquisition and fulfilment of orders. Above all, the main difference between both tools is that PDM systems for the most part do not provide an adequate support to sales product configuration. On the other hand configurators, by their very mission, do not specifically support workflow management in the context of the product development process (see figure 2).

Since PC and PDM systems deliver specific functions, they may have to be both implemented when ample product variety is offered. This automatically raises the issue of system integration, because, as discussed above, they jointly deliver three high-level functionalities that are critical for product variety management: the creation of variant-specific documents, the classification and coding of variant-specific information and the management of workflow in the product configuration process.

The key element connecting PC and PDM systems is the configuration model, as described in section 2, both in its technical and sales constituents (see figure 2). The technical configuration model, in fact, permits the definition of the different relationships between the multiple parts of the product, helping to specify product documents and associating them with a specific product variant. Likewise, it classifies stored product data according to various attributes, thus supporting data retrieval and maintenance; functions that are going to be intensively used when customized products are offered. The sales configuration model, instead, guides workflow management in the context of order acquisition, as it defines what information has to be collected, who or what entities have to input it, in what sequence and subject to what controls and approvals. Hence, the sales configuration model has to be consistent with the workflow management rules and principles embedded in the PDM system, rules and principles that guide the release of product, project and part documentation more in general.

4. Customer relationship management systems and product configuration systems

The product configurator plays a key role in supporting the interaction with the customer when customized products are offered. However, the goal of managing the relation with the customer in an integrated way is pursued by the so-called customer relationship management (CRM) systems (Reinartz *et al*. 2004, Wilson *et al*. 2002). Therefore, this section is aimed at exploring how CRM systems support efficient and effective customization and, additionally, how these functions relate to those of a PC system.

4.1 *CRM functions*

Essentially, CRM is an IT-supported managerial approach focused on the relationship between the company and the customer (Ryals and Knox 2001, Reinartz *et al*. 2004, Dowling 2002). CRM applications support activities of

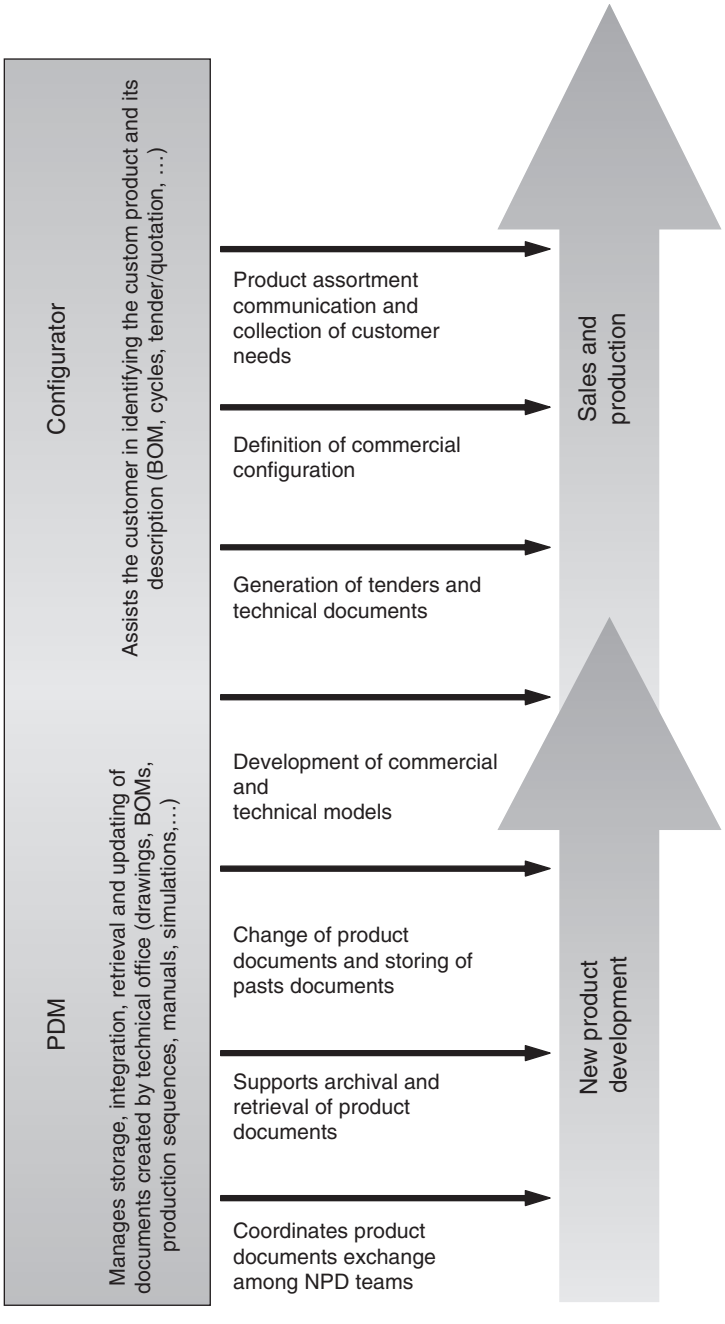

Figure 2. Comparing product configurators and product data management systems functionalities.

customer care and service, sales force, and marketing (Croteau and Li 2003). The basic idea is that by managing the customer–company relationship, which changes in time and is specific for each customer, the company will be able to improve its profits (Ryals and Knox 2001, Reinartz *et al*. 2004). CRM can obtain such a goal by means of three functions:

- Improving the way new customer relationships are started.
- Streamlining existing customer relationships.
- Studying and redefining existing customer relationships.

According to CRM, the relationship with the customer must be carefully managed through all its stages starting from its very beginning (Dwyer *et al*. 1987, Reinartz *et al*. 2004). In fact, choosing the appropriate customers (Winer 2001) and giving them a positive impression from the start, allows the company to save time and avoids the risk of losing potential customers. Research into electronic commerce–customer relationships has proposed appropriate guidelines for developing web sites that dynamically recognize customer characteristics and tailor the customer-company interaction (Romano and Fjermestad 2002, Albert *et al*. 2004).

Faithful customers are an asset for a company (Reichheld and Sasser 1990). They place orders absorbing minimal commercial resources, because they are familiar with the company and its products. They stay with the company also when the economy is bad, thus guaranteeing a capacity utilization and coverage of fixed costs. Hence, faithful customers constitute a stock of assets that the company has a strong incentive to expand and maintain (Blattberg and Deighton 1996, Filiatrault and Lapierre 1997, Reichheld 1996). CRM, accordingly, aims at making life easier to its faithful customers, thus discouraging them to switch to a competitor (Dowling 2002). The mechanisms through which CRM streamlines the relation with customers are multiple and implies cross-functional integration (Ryals and Knox 2001). For example, when a customer calls to find out the status of her order the salesman should have updated feedback from factory control, to understand whether manufacturing is on time or not. Were the salesman to notice a delay, he should be able to track down the reason for the delay. An accounting profile of the customer may be needed, to understand if this order has been frozen because of bad credit. Alternatively, he may need to find out who picked the order and committed to that delivery date. Finally, they may have to check whether delay was due to the backlog of paper going to and from the customer's and the supplier's technical offices.

CRM supports marketing planning by means of the most accurate data on customer relationships (Zeithaml *et al*. 2001, Ryals and Knox 2001, Croteau and Li 2003). How marketing actually uses such data is constrained only by imagination: screening market trends, tracking and improve customer relationships, assessing changes in customers' logistical requirements, etc. For example, a company that manufactures boilers classifies its customers i.e., installers according to their profitability and, based on this value, the company offers a series of added services such as training courses, smoke analysis devices, financial aid to purchase vans, etc. The more profitable a customer, the wider the range of services he can obtain from the company.

4.2 *How CRM functions contribute to product variety management*

CRM offers a number of opportunities to efficiently and effectively customize products, through all its functions.

Improving the ways new customer relationships are started. In the first place, to contact potential customers and persuade them to buy is a crucial and difficult task, especially when a high variety of products is offered. Under these circumstances, in fact, it is more difficult to understand what the customer actually needs and to communicate, in a convincing way, what the company is offering. Customized products require an intensive communication with the customer, which implies longer times and increased efforts in order to establish a customer–supplier relationship. Since CRM systems allow us to orderly and systematically collect information on new potential customers, they help the company to get an earlier and more precise picture of the specific needs of a customer.

Streamlining existing customer relationships. Secondly, product variety intrinsically works against the objective of streamlining customers' relations, because it reduces repetitiveness in sales and order fulfilment processes. Lower repetitiveness is likely to result in errors and delays even when dealing with existing customers, potentially compromising established relations. Since CRM puts all customer-related information in the hands of who is keeping the customer contact, interactions with the customer take place without errors or delays in retrieving this information. For example, in a case where a company is serving a multi-plant, multi-country customer, the CRM system may ensure that customer-defined freight documents are tailored each to specific destination.

Studying and redefining existing customer relationships. When it comes to redefining a relation with an existing customer, product variety is a major source of complexity. On the one hand, when multiple attributes can be specified by customers, it becomes important for the company to understand what attributes can be trimmed, as they add to complexity and cost without really fulfilling the customers' needs. On the other hand, the question arises as to what attributes are missing in the company's product space that customers would like to have and would be willing to pay for. In both cases, as CRM consolidates large amounts of customer data, it provides valuable information about attributes that have to be cut or added.

4.3 *CRM PC systems for product variety management*

When custom products are offered, an effective CRM system requires either a close integration with a PC or it has to embed a PC itself. In fact, when custom products are offered, the interaction with the customer has to deal with product-related issues as well. After all, customization is intrinsically a relationally-intensive activity. Consequently, when product customization is offered, it is unthinkable for a CRM

system not to include some of the typical features of a configurator. The modalities through which PC features contribute to perform each one of the three CRM functions are synthesized and explained hereafter.

Identification of best fit between the needs of a new customer and the company product offer. When potential customers contact a company for the first time, they need to learn what product families, variants and options are available. At the same, they cannot invest too much effort on this learning process. The sales dialogue of a configurator, indeed, specifically serves the purpose of helping customers to browse the company's product offer. It does so by describing the product, structuring the interaction with the customer, simplifying choices and by making the customer appreciate the value of available alternatives (Salvador and Forza 2004b). Moreover, the configurators, being highly interactive, foster the customer's learning process, ultimately supporting customers in their choice processes.

When the salesman contacts a customer for the first time, he does not have any precise idea of their needs. Contact after contact, he collects more and more information about the customer's needs and preferences. By collecting this information on simple sheets of paper, double-entry tables, pre-printed forms, etc, the company is exposed to a number of potential problems. Incorrect information may be collected and stored, important information may be lost or forgotten for good (Forza and Salvador 2002a, 2002b, Salvador and Forza 2004a). No doubt, this is not the best way to start a relationship. The sales dialogue of a configurator, instead, offers a way out of all these problems. The information collected is virtually error-free, as questions should be made unambiguously, and replies should comply with appropriate constraints. Useful information, such as intermediate configurations that did not fully meet customer needs can be stored and retrieved in case the customer goes back on his previous choices. Finally, all the necessary information should be collected, as the configurator may not release any configuration until all the required attributes have not been specified.

Identification of past configurations and standards of extant customers. Product customization increases the amount of information needed when the company interacts with its customers, thus posing stringent product information management requirements on CRM systems. Prerequisite to managing information on customized products is accurate storage of all product specifications concerning past and current product configurations offered to each specific customer. Product configurators provide managers with this capacity.

A possible use of past product configurations is in the after-sales service. When a customer needs a spare part for a customized product, the key issue is to precisely identify the spare part compatible with the specific product configuration in question. For example, if a bathtub manufacturer field service receives a call to replace the pump of a five years old jacuzzi, one must know what kind of pump was installed in that product. This may be problematic where the invoice does not indicate bathtub components. If a product configurator was used when selling the tub, by recalling the product code (indicated in the invoice) it would be easy to trace back to the specific pump

installed. In the case of late or erroneous replacement of the pump, the customer will most likely write off the company.

Past product configuration data can also be used to speed up configuration activities of faithful customers. In fact, customers tend to have their own 'standards', i.e. the configuration requested by a given customer often share some common requirements. In this case, they expect the company to remember their usual requirements, making life easier when placing an order. Product configurators may favour the creation of a customer profile, and in this way the company is able to offer the customer, by default, their favoured or typical options.

Analysis of product features for redesigning product offer and customer relations. Product variety adds to the bulk of information CRM has to manage and it increases the complexity of possible analyses aimed at redefining existing customer relationships. To give an idea of possible difficulties, just think of a segment of customers that stopped making orders last year. Let's say they are unsatisfied with the product. What's wrong with the product? What attribute? Or what set of attributes?, etc. Answering these questions implies having accurate descriptions of those features of products sold in the past to each customer. Product configurators make this information easily available.

A fundamental use of data on customer relations is to calculate how much each relationship is profitable since a fundamental CRM assumption is that customer value for the firm may differ from customer to customer (Winer 2001, Reinartz *et al.* 2004). Managing the profit obtainable from a customer may be a viable approach also in markets where close relationships or completely loyal relationships are not the most convenient objectives to be pursued (Dowling 2002). Calculating profitability per relation, when products are customized, cannot be done without precise data on past product configurations. For example, sales data on past product configurations allows the computing of accurate product variable costs, as well as other product costs, e.g. the cost of customer-specific product certifications. Calculating profitability per relationship requires also other non-product related data, outlining the cost of the customer–supplier relationship. Not all relationships, in fact, have the same cost. For example, some customers may take a long time to make up their minds about exact product specifications, so that they adsorb the supplier's sales resources. Other customers may precisely know their needs and, consequently, minimally absorb the supplier's sales resources. Supported by configuration data, therefore, CRM can help the company to screen customers, supplying information on what relationships have to be fostered or trimmed.

As well as supporting the management of 'customer relationships' CRM systems often include business intelligence tools (Croteau and Li 2003). Such tools are intended to analyse raw data on customer relationships providing synthetic figures needed by high-level managers (Winer 2001). For example, they may supply information on sales by customer segment, by region, etc. When custom products are sold, data on past product configurations are very important to perform such analyses. For instance, by analysing the requests for 'special orders', it may be possible to understand what additional features should be incorporated in the sales dialogue. On the other hand, it may be useful to assess what features are seldom required by customers, so that it may be appropriate to drop them from the

sales dialogue. When custom products are offered, therefore, to get the most from the business intelligence tools included within CRM systems, accurate sales data on past product configurations are needed.

PC and CRM are therefore complementary systems when product variety is offered. This complementarity derives from the fact that three key CRM functions supporting the management of product variety (see figure 3) are best delivered by a product configuration model, an essential component of PC systems. Both the sales and the technical constituents of the product configuration model are critical for the successful execution of CRM tasks when many product varieties are offered.

The sales configuration model increases the effectiveness of a CRM system in a number of ways. First of all, it lays the basis of a sound customer relation by, first and foremost, explaining clearly what the product being offered is and what the possible alternatives are. Additionally, a sales configuration model effectively supports the interaction with the customer (1) by describing the product at the appropriate level of detail/abstraction, (2) by asking questions according to a sequence perceived as natural by the customer (3) by proposing alternatives that take into account previous customer's choices/preferences and (4) by allowing the customer to interactively learn about available solutions to his problem.

Also the technical configuration model and the association of its elements with the sales configuration model enable the performance of a number of analyses critical for the successful operation of a CRM system when high product variety is offered. For example, when precise information relating past customer choices with product and process data is available, it is easier to systematically compute profitability per product per customer. Based on this information, the company may decide what product features to trim and what to push, as well as what customers to support and what to drop. If these data are available, but are not stored according to the logic of product configuration models, then the analysis may become so complex that a considerable amount of approximation has to be introduced. Ultimately, poor decisions would likely to be made.

5. Discussion and conclusions

In this paper we have considered three main IT-based systems that support product variety management. We propose a systematic view of the high-level product variety management functions of these systems, pointing out overlaps, specificities and synergies among these functions. We have shown that each of these three systems supports product variety management in a specific way. Likewise, a number of overlaps, interactions and synergies exist among these systems.

We have shown that the fundamental *trait-de-union* among PDM, CRM and PC systems, meant as tools for product variety management, is the product configuration model. The product model is conceived in the context of PDM, as it serves the purpose of collecting the information used and created within the product development process in a structured and rational way. The product model is then used by the PC in order to generate product variant-specific documents based on customers' specifications. Finally, the product model is a prerequisite for managing product variant-specific customer's information in a disciplined way, both in the day-by-day management of the relation and when it comes to redefining the relation

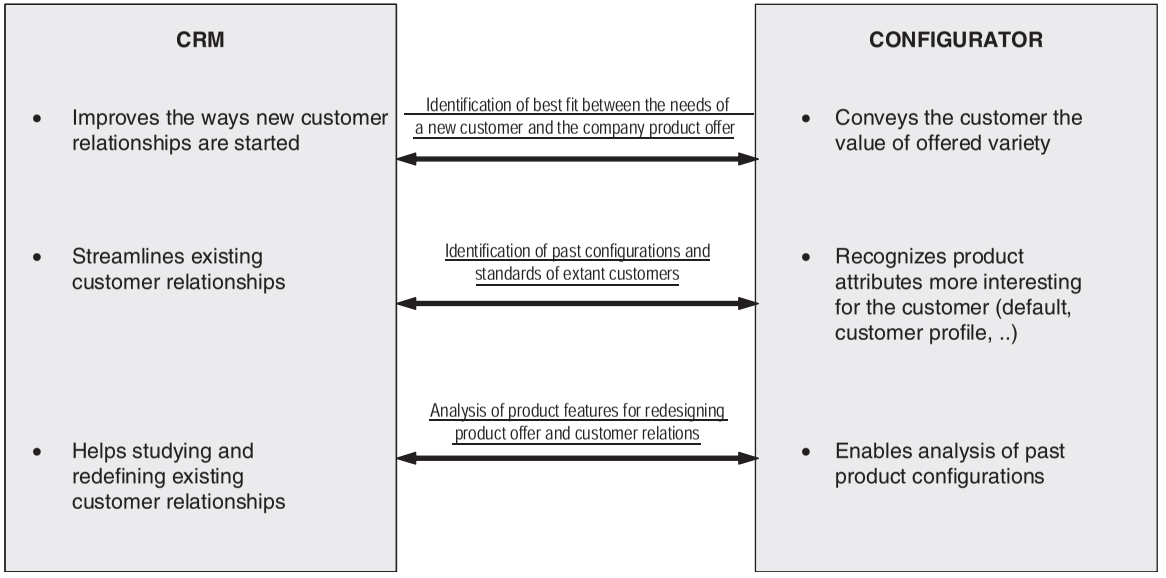

Figure 3. Comparing product configurators and customer relationship management systems functionalities.

by redefining the product assortment. Pragmatically, if a company faces product variety management problems, the adoption and implementation of a PC cannot be taken light heartedly, as this will constrain the effectiveness in managing customer relations and in managing product documents.

We see a great opportunity for management research as well as for application research to investigate the possibilities offered by the integration of the three considered systems. For example, we are currently missing a general theory on how product proliferation impacts the information management requirements placed upon a company and its information management infrastructure. Such a theory would undoubtedly be valuable as a guide to develop integrated applications supporting the information processing, storage and retrieval needs of companies pursuing mass customisation strategies. The present paper moves a step forward in this direction, framing the product model as a cornerstone of such information management infrastructure in the context of product variety management, or mass customization. Ultimately, the formalization of a product model is the technical answer to the requirement that mass customization has to be based upon the pre-defined product space (Tseng and Piller 2003).

In terms of application development, the present paper highlights the importance of creating integrated applications that serve the needs of different functional areas within the company when product variety is offered. This is particularly critical when we consider the integration of CRM tools with PDM and product configurators. CRM tools, in fact, often grow independent of the information management infrastructure supporting the company's operations. Failing to capture potential synergies across CRM, PDM and product configuration systems in the domain of 'customer acquisition', 'customer retention' and 'customer relationship re-definition' would ultimately reduce the effectiveness and efficiency of the information system infrastructure supporting product variety management.

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