A comprehensive product model for mass customization

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Nowadays, the customer oriented business model and the stress on performances lead a lot of enterprises to adopt the Mass Customization (MC) (Davis 1987) model. The two-sided nature of the MC concept can be identified in (Tseng and Jiao 2001) or (Blecker et al. 2004): ideally MC is a business approach that want to provide the product customization capability like an engineer-to-order organization (ETO – the product is designed at each order entry), preserving a mass production efficiency.

In this paper, we focus on the link between customer needs and the customized product to be realized in order to fulfil them, i.e. we do not deal with methods for managing product variability at the shop floor level. To formalise this link, a commonly accepted solution is to place, during the order entry process, between the customer and the product to be manufactured, a configuration system (based on a product model) in which customer can enter values for some options in order to define a product. This kind of systems is able to create manufacturable products based on configuration rules formalized by designers. At the design stage, the manufacturability of all possible customized products is verified. Usually, this kind of product model is named in many different ways, e.g. *product family* (Hong et al. 2008), *configurable product model* (Aldanondo and Vareilles 2008) or *product line* (Pohl, Bockle, and Van Der Linden 2005; Mazo et al. 2012). The name *Product Line* (PL) will represent here all these types of models.

PLs have to be able to identify a link between needs expressed by customers and the corresponding customized product that can be manufactured by the enterprise. Current works on PL can be classified on the distance between the customer needs and the input of the PL (i.e. values of proposed options required by the system to configure a product). Three groups, based on the main system definition models (i.e. requirements, logical architecture, physical architecture) (Pyster et al. 2012) can be identified on the basis of this dimension:

* *Product component features* (i.e. physical architecture) as input (e.g. (Zhu et al. 2008): at this stage the customer (not supposed to be an expert) is not able to understand the interaction between components and evidently he is not able to understand their impacts on his needs;
* *Product functions* (i.e. logical architecture)as input (e.g. (Li et al. 2006)): the customer is not able to know how functions can satisfy its needs and especially about how functions interact for doing so;
* *Product specification (i.e. requirements)* as input (e.g. (Qin and Wei 2010; Hong et al. 2008)): to the customer is provided the knowledge about the effects of how the product functions (and so product components) interact for performing the product behaviour, of which specifications are the description; in this case, the customer still is not able to know the impact of the product specification on his needs.

Starting from this classification, we can identify a gap to be filled in order to formalise the link between customer needs and system requirements. In order to fill this gap, in the configuration system:

* manufacturers can use market research (e.g. (Helo et al. 2010)), but therefore the manufacturer designs the products and after looks for potential customers;
* manufacturers can optimize customer satisfaction (e.g. (Hong et al. 2008)), but that implies they are able to represent and to assess the feeling of satisfaction of each customer;
* a seller is charged to fill this gap, performing a real requirement analysis process (Haskins, Forsberg, and Engineering 2011);
* in the worst (but very usual) case, customers have to fill this gap.

Other approaches, from the business sciences (Bergvall-Kareborn et al., 2009; Stahlbröst, 2008), are involving customers in each design stage. But, for instance, let us consider the case of an air-conditioner manufacturer, the question to put to the customer is: *how is the air that you want to breathe?* In our opinion, customers are not able to answer at this kind of questions.

We are not reinventing the wheel: MC has existed for more than twenty years. However, if for simple product, a customer can imagine its impact in his life, what about complex *systems* (Von Bertalanffy 1956)? We are convinced that customers have to be expert only of their environment. Therefore, in this work, we propose a method to build more comprehensive PLs able to formalize the link between the customer environment and the configured products.

Here we propose a method based on definitions such as *system*, *environment*, *interaction*, *purpose* and *black-box* coming from cybernetics (Wiener, 1965) and system theory (Le Moigne, 1994). The aim is to define how to identify a system purpose. And how starting from this purpose, an engineer can identify needed interactions between the purpose fulfilment and the system features (i.e. the goal of the configuration process). Here the system to be configured is seen like a *black-box*, because in the MC scenario, we suppose that the link from the system specification (i.e. the product offer of a company) and the manufactured product (i.e. how to manufacture offered products) is built during the design stage (and not at each order entry, i.e. MTO). In order to represent a PL we use a mathematical representation typical of control theory, i.e. *state-space models* (Levine, 1996) as follows:

* The *analysed system* (of the state-space model) is the customer environment (e.g. customer room to heat)
* *Input functions* represent the environment description (made by the customer information) and configured system specifications (e.g. features of the air-conditioner);
* *States functions* represent how the configured system interact with the customer environment;
* The *output function* is based on state values in an instant of time.
* A set of defined state values (e.g. room temperature, humidity) or one output value (e.g. air comfort) defines the *purpose* of the configured system.

In order to define this model, we have to fix a well-defined purpose (e.g. values for humidity and temperature of the customer room). By means of the domain knowledge, the engineer identifies interactions between the customer environment (e.g. room orientation and placement in the building, room usage, etc.) and the system specifications (e.g. features of the air-conditioner to be configured). These interactions have to be formalized as state functions. At each order entry, a customer describes its environment and therefore defines the input functions concerning that. Starting from these input functions, state functions and the purpose values, we can identify functions related to the specification of one system in the PL. Deploying this method customer has only to describe its environment to configure the right product (from the engineer point of view).

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