Computers in Industry 75 (2016) 101–115

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

# Complex product modeling based on a Multi-solution eXtended Conceptual Design Semantic Matrix for behavioral performance assessment

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ARTICLE INFO

*Article history:*
Received 15 October 2014
Received in revised form 25 May 2015
Accepted 3 June 2015
Available online 28 July 2015

*Keywords:*
Complex product modeling
Conceptual modeling
Semantic modeling
X-DSM
X-CDSM
MSX-CDSM
Behavioral performance assessment

ABSTRACT

The modeling of complex products is a practice increasingly used at the early design stage. Geometric 3D modeling is widely used in CAD software for complex products. However, data extracted from such models do not contain all relevant and necessary information to assess the behavioral performance of complex products. Several studies have focused on the use of design structure matrices (DSM) for the representation of this information. The component-based DSM allows a visual and compact representation of mechanical products. It gives the list of components and shows the links between them. The designer can also enrich a product model using such a DSM representation. However, we note that, until now, a component-based DSM represents only one instance of a specific product. In this paper we propose an extended DSM approach which includes additional information to model several product families. Thus, from the design specification we build the space of solutions then we determine the domain of eligible solutions. We represent these different eligible solutions in a Multi-solution eXtended Conceptual Design Semantic Matrix (MSX-CDSM). The implementation of such a matrix is introduced to assess behavioral performance of complex products at the early design stage.



## 1. Introduction

The complexity in product development projects can emanate from multiple aspects: the product's design, the process of development, the management of knowledge, the tools and technologies applied, the requirements to be fulfilled, and other factors. For each factor, the complexity arises from the numerous elements and their relationships such as those between the components, those between the activities to develop them, and those among the actors that perform these activities [1]. Complex product design and development has evolved in recent years to utilize new technologies and to apply new practices to create new products better and faster than ever (development speed, digital processes, platform flexibility, complexity management, outsourcing and offshoring, customer involvement, innovation networks, sustainability, etc.) [2]. The range of products increases and as products are customized, the number of possible combinations of parts or components rises dramatically. This situation, named mass customization, is not well handled by traditional representations of products where each variant is treated as a different product [3]. Many studies have focused on the use of ontologies to model complex products [3–5]. Others have focused on the use of the DSM approach for the modeling of complex products (see Section 2). However, we note that, until now, the component-based DSM has been used to model only a single product. It allows the representation of the product's components and shows if there are links between components or not. In such a DSM, components are represented by instances and between two components the matrix provides information about the presence or the absence of link. This kind of matrix is poor because it fails to represent all relevant and necessary data about component's characteristics and link types. We propose in this paper to extend the DSM modeling approach and to combine it with the object-oriented modeling approach in order to model several families of complex products. In this approach, the inputs

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http://dx.doi.org/10.1016/j.compind.2015.06.003
0166-3615/

of the DSM are component classes and link classes that allow adding semantic data. We call such a matrix Multi-Solution eXtended Conceptual DSM (MSX-CDSM). This matrix can be used to represent different solutions and the corresponding component instances. We then obtain a meta-matrix which represents several product families (solutions) and several variants of each family (instances). The purpose of our approach is to have an open and large field of exploration of solutions. This meta-matrix contains semantic data that allows the designer to perform complex product behavioral performance assessment.

To do this, in Section 2 we present some significant studies dealing with product modeling using the DSM. In Section 3 we give the characteristics of components and links of mechatronic products and the relationships between them with the SysML block definition diagram. The definition of the X-CDSM is given in Section 4. The MSX-CDSM is defined and its implementation is introduced in Section 5. Then, we model a complex product with this kind of matrix in Section 6. In this section, we also illustrate the contribution of such a model to the assessment process of behavioral performances of complex products. Finally, we give a conclusion and the direction of our future work in Section 7.

## 2. Related work

The complexity of modern products may result in a number of components and links between them (structure) and/or the number of technologies combined (Multi-disciplinary) [6]. Several studies have focused on the modeling of complex products using DSM. Thus, Coulibaly et al. used DSM to evaluate maintainability of mechanical products at the early design stage [7]. To facilitate decomposition and modularity of products Hong et al. coupled the Design Structure Matrix (DSM) and the Axiomatic Design Matrix (ADM) [8]. This enabled them to model physical links between components of complex products, but also relationships between functional requirements and components. However, this methodology can only be applied to systems already designed. Relationships between the model of a system and its DSM have been presented by Sharon et al. [9]. To capture traceability of a product's design knowledge, Tang et al. used the DSM modeling approach [10]. A DSM-based approach allowing the decomposition of products into several sub-assemblies is given by Deng et al. [11]. DSM is also used to materialize relationships between functions and parameters of products [12]. This is a modularization approach based on DSM. It allows the protection of a product critical information. DSM is used to model the physical structure of multi-component products in order to give a new FBS (function–behaviour–structure) product behavioral approach [13]. Other studies deal with the use of ontologies [3–5], Petri nets [14,15], queueing networks [16], genetic algorithms [17,18] or other tools either to enhance product assembly and/or disassembly processes or to evaluate and predict product's behavioral performance. However, we note that in all these studies, none has proposed to combine DSM and object-oriented modeling in order to model in the same matrix several families of complex products.

Section 3 gives a SysML model in which classes of components and classes of links of mechatronic products are characterized and the relationships between them are shown.

## 3. Representation of components and links of complex products

Complex products can be considered as a network of components that share technical interfaces (links) in order to function as a whole [19]. These components and links are characterized by properties, methods and constraints. Thus we can represent them by classes using an object-oriented modeling formalism. In Fig. 1 the classes of components and the classes of links are represented and the relationships between them are shown. In this figure some properties and methods allowing characterization of these classes are given. According to specifications other properties and methods can appear.

Fig. 1 gives a description of the components and links of a complex product. In this figure, we have the relationships between the product and its sub-assemblies and links. The relationships between a sub-assembly and its sub-components are also represented. The representation of the classes of components and links in the X-CDSM is given in Section 4.3. They represent the inputs to the X-CDSM (eXtended Conceptual Design Semantic Matrix) defined in Section 4.

## 4. eXtended Conceptual Design Semantic Matrix (X-CDSM)

In this section we show the successive enhancements of the component-based DSM approach for the representation of several solutions and several instances of each of them. In fact, a first enhancement of the traditional component-based DSM is proposed by Coulibaly et al. [7,13]. The new matrix obtained is called extended DSM (X-DSM). In our studies, we propose an enhancement of the X-DSM which consists of two steps. The creation of the X-CDSM described in Section 4.3 and the creation of the MSX-CDSM described in Section 5.

### 4.1. Component-based DSM

A traditional component-based DSM aims to represent the structure of multi-component products. It is a square matrix that gives a simple, compact and visual representation of a system or project [20]. It can be static or dynamic (temporal) [8,9]. The temporal DSM has been studied by Browning in [21]. In this paper we focus especially on the component-based DSM. Indeed, this kind of DSM allows the representation of links between components in non diagonal cells [7,13]. In such a DSM, each component is represented by a row and a column (Fig. 2). However, a component-based DSM gives a poor representation of complex products because it does not give the characteristics of the components and the links. Only the presence or the absence of links between components is represented.

If we denote $D_{ij}$ the cell in the intersection of the row $i$ and the column $j$:

- If $i = j$, $D_{ij}$ contains the component $C_i$ ($C_{ii}$). $C_{ii}$ is a unique instance of component;
- If $i \neq j$, $D_{ij}$ contains the link between the component $C_i$ and the component $C_j$ ($V_{ij}$).
  - If $V_{ij} = 1$, there are links between $C_i$ and $C_j$;
  - If $V_{ij} = 0$, there are not links between $C_i$ and $C_j$.

To improve the representation of complex products with DSM, the traditional component-based DSM has been enriched by Coulibaly et al. [7,13].

### 4.2. eXtended component-based DSM (X-DSM)

In their studies, Coulibaly et al. [7,13] have proposed an enrichment of the traditional component-based DSM. A new row that contains the number of links for each component and as many columns as necessary (criticality, reliability, environmental impact, etc.) for the component and the link characterization are added to the traditional component-based DSM. The semantic data enhances the description of complex products and improves their behavioral performance. This kind of matrix is called