

Engineering Change Management: A novel approach for dependency identification and change propagation for product redesign

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Abstract: During their life cycle, products can be re-designed due to the requested changes. One or more changes can be applied to the products in order to improve, upgrade and adapt it to new requirements. These changes can have serious impacts. For one design change, some impacts can be predictable while others occur due to unexpected propagations on other parts of the product. Dealing with this risk, companies look for an approach to evaluate and model the propagation of changes impacts to minimize their consequences. The main objective of this work is to characterise this change impact by identification of the dependencies among product components, which is a first and necessary step to evaluate change propagation. We develop a novel approach based on Design Structure Matrix and graphs to identify and characterise the type of dependency existent between product parameters and compute the change propagation impacts. Our findings show that functional dependency is more detailed than quantitative and qualitative dependency characterisation, already used in the literature. A case of 2D geometric model of bicycle is presented at the end of paper.

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1. INTRODUCTION

The re-design of an existing product is a common need for many industries. The model of the modified product is generally derived from the existing one, changing only few design parameters. A product may be viewed as parts and sub-systems closely linked and susceptible of changing to answer new requirements provided at any phase of product life-cycle. Designers have to adapt or upgrade the product by changing one or some of components or functions. However, this renewal is rarely simple and a small change in one element can cause many changes that can have serious impacts to the other components. Engineering Change Management (ECM) deals with identifying and predicting change propagation (Jarratt et al., 2011). Among others, modelling or characterising of the inter-dependencies of design parameters or variables is one of the key issues in ECM. This is the main goal of this paper. We will take advantage of Computer-Aided Design (CAD) packages and their ability to calculate the impact of one component's changes to others, to identify quantitatively and qualitatively the dependency among all components.

This paper is organised as follows. In next section we will browse a concise literature review. In the third section, we propose our 2 steps approach to first characterise the dependency relations, in quantitative, qualitative and functional manners, between elements in a geometrical product design. Then, the changes are propagated among

the product parameters. Results of our proposed approach are then presented in section four. Finally, section 5 provides conclusions and outlines future directions for the research.

2. ENGINEERING CHANGE MANAGEMENT (ECM)

It is necessary here to clarify exactly what is meant by Engineering Changes. Jarratt et al. (2011) have provided the most complete definition to Engineering Change: "An engineering change is an alteration made to parts, drawings or software that have already been released during the product design process. The change can be of any size or type; the change can involve any number of people and take any length of time."

When considering engineering change (EC) in the literature, many authors have proposed tools and methods to characterise dependency, evaluate change impact and propagate it. Interested readers could refer to (Hamraz et al., 2012) and (Jarratt et al., 2011) for an extensive state of the art of these methods and tools.

To deal with ECM, some authors rely on Design Structure Matrix (DSM) to model and manipulate the dependencies by matrix, others use the dependency graph. One of the most famous matrix-based approaches is the Change Prediction Method (CPM), cf. (Clarkson et al., 2004). CPM analyses change behaviour by developing mathematical models and express the risk of change propagation by using likelihood and impact matrices. Finally, the risk is

computed by the multiplication of these two parameters. In another approach (Kusiak and Wang, 1995), authors propose a methodology to assist designers in negotiation of constraints providing a qualitative and quantitative characterisation of dependency. In the next sections 2.1 and 2.2, we focus on dependency characterisation and EC propagation respectively.

2.1 Dependency characterisation

Change propagation impacts can be evaluated only after the characterization of dependencies has been done. This characterization can be qualitative: to give insight on the potential variations of a parameter without seeking for their values. Qualitative characterization was presented by (Kusiak and Wang, 1995) as a determination of the change "direction" (increasing, decreasing, null or unknown) of a variable affected by another one. In the same context, (Chua and Hossain, 2012) and (Cohen et al., 2000) added qualitative values (low, medium and high) based on empirical expertise. Dependency can be also characterized quantitatively where correspondent methods seek to determine the new values of variables generated by the occurrence of a change. (Cheng and Chu, 2012) and (Kusiak and Wang, 1995) used quantitative dependency to compute the rate of changes. A second use of quantitative characterization is given by (Clarkson et al., 2004) and (Hamraz et al., 2013a) where random variables, called "likelihood", are defined to model the probability of change occurrence. And deterministic impact values stand for the efforts required to integrate a change in the target node, for instance see ((Keller et al., 2005), (Kim et al., 2013), (Hamraz et al., 2013a) and (Rutka et al., 2006)). According to (Hamraz et al., 2013b) this approach presents two limits: (i) the used model is subjective, and (ii) the CPM method defined by (Clarkson et al., 2004) provides a static model in which the impacts of change are captured once and the predictions are not updated during propagation. Several approaches have been proposed to identify qualitatively and quantitatively these dependencies, but none of them try to capture the relation as a function; often it is seen as a black box. This brings us to the major shortcomings of such approaches. The approach proposed in this paper looks to find the right trade-offs among too much detailed change management models and too much simplified ones.

2.2 EC Propagation

Once the dependencies are characterized, a change can be propagated and a representation technique is needed. Dependency graphs can be employed as a technique for showing change propagation directions. One interesting approach is to show the propagation paths, beginning from a root node to target nodes, see (Keller et al., 2005) and (Rutka et al., 2006). A path starts from a change source and the propagation ends when it reaches a frozen node or if the limit number of propagation steps is reached. Some authors have focused in particular on visualizing change propagation using indicators that characterize the propagation. (Kim et al., 2013) proposed a change propagation index (CPI) ranging from -1 to +1. This index indicates the direction of change propagation (increasing or decreasing) and is used to analyze components individually, classify their behaviors, and decide which components should

be changed while redesigning the product. A component's behavior is then classified into multipliers, absorbers and carrier, as described by (Eckert et al., 2004), depending on its CPI value. Similarly, (Cheng and Chu, 2012) developed three assessment indicators based on the centrality concept of weighted networks: (i) degree-changeability to assess the direct change degree, (ii) reach-changeability that measures the indirect change, and (iii) between-changeability to define the parts located strategically on the communication paths linking other pairs. These centrality measures can identify the most important nodes of the network based on their interactions and influences. Finally, (Yang and Duan, 2012) proposed the change propagation scope, defined as the sum of changed direct parameters and changed target parameters for every specific change. An optimal change propagation path is found by choosing the solution with the smallest scope of propagation.

3. GENERAL APPROACH

In the context of product redesign or upgrade, three steps are logically followed to study and evaluate a change request (see Figure 1). During the first step all the required dependencies between system elements are identified. Then a required change is propagated through the change propagation paths to other elements and impacts are assessed. Finally, in a third step, analysis are performed and decisions are made by designers and experts to redesign the product, knowing the possible consequences of the change. Steps 1 and 2 will be defined hereafter; step 3 shows the use of the insights obtained in step 2 which is context-specific and not developed in this paper.

3.1 Step 1: Dependency Identification

The dependencies are identified by following six stages, as presented in Figure 2.

First of all, we need to model the system. As mentioned earlier, we focus on 2D geometrical modelling here. Therefore, the system model is defined by its different parameters (lengths and angles) and their associated constraints. This model should be simulable by using a CAD tool. Here CATIA is used as the simulation tool.

For every parameter of the model (which can be either length or angle) we will proceed by a so-called free change simulation or simply free simulation (stage 2). Iteratively, one parameter is selected and changed within its definition domain while collecting the other parameters values provided by CATIA. All these results are represented in a three dimensional Matrix D .

In the third stage, we discover the first set of dependent parameters and define then the Binary Dependency Matrix B analysing D . The components of B express whether dependencies do exist between the considered parameters or not.

- **The Binary Dependency Matrix** noted $B = [b_{i,j}]_{1 \leq i \leq n, 1 \leq j \leq n}$ is defined by:

$$b_{i,j} = \begin{cases} 1 & \text{if } v_{i,j} \neq 0 \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where $v_{i,j}$ represents the variance of the new values of parameter p_j after the change of parameter p_i . Variance measures how far a set of numbers are spread out around

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