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# **A Design Structure Matrix (DSM) -based method for dependency characterisation in Engineering change management (ECM) domain**

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**Abstract** – During the product's life cycle, it can be re-designed due to received requests for new improvement. One or more changes can be applied on the product in order to adapt or upgrade it. These changes can have serious impacts. Some of the change impact can be partly predictable while some other unexpected propagation of the change can still occur. Despite this risk, the industry does not currently have a clear approach to evaluate and represent the propagation of changes and minimize their consequence. 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 to identify and characterise the type of dependency existent between two dimensions. Findings show that functional dependency is more detailed than quantitative and qualitative dependency characterisation, already used in the literature.

**Key words:** Engineering Change Management / Re-design / Dependency / Regression Analysis.

## 1 Introduction

The re-design of an existing product is a common need for many industrials. 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 lifecycle. 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. [3] 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 dependency identification method to characterise the dependency relations, in quantitative, qualitative and functional manners, between elements in a geometrical product design. Finally, conclusions and perspectives of coming works are presented.

## 2 Literature review

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 [2] and [3] for an extensive state of the art of these methods and tools. To deal with characterising dependency, 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, refer [1]. 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 [4], authors propose a methodology to assist designers in negotiation of constraints providing a qualitative and quantitative characterisation of dependency.

To conclude, most of the approaches for modelling the changes use a design structure matrix. This matrix can carry additional information to

characterise the nature of a dependency between two elements. This information can be Boolean (existence), numerical (quantitative) or qualitative. Several approaches have been proposed to identify 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.

## 3 Dependency characterisation method

The whole process of our method can be summarized in four steps: System modelling, Change definition and simulation, Dependency characterisation and Results interpretation. [5]

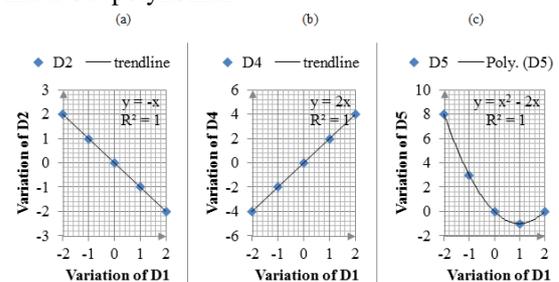
After simulating all the possibilities of change on different dimensions, in step two, we identify the type of dependency between the dimensions pairwise.

Let us suppose that the model contains five dimensions and  $D_1$  is the instigating dimension. These results can be represented in Table 1. Each row contains an instance of a change on  $D_1 \in [D_1^0 - 2; D_1^0 + 2]$  with a sampling step  $\sigma_i = 1$ .

**Table 1.** Example of one change results given different changes on D1

D1	D2	D3	D4	D5
$D_1^0 - 2$	$D_2^0 + 2$	$D_3^0$	$D_4^0 - 4$	$D_5^0 + 8$
$D_1^0 - 1$	$D_2^0 + 1$	$D_3^0$	$D_4^0 - 2$	$D_5^0 + 3$
$D_1^0$	$D_2^0$	$D_3^0$	$D_4^0$	$D_5^0$
$D_1^0 + 1$	$D_2^0 - 1$	$D_3^0$	$D_4^0 + 2$	$D_5^0 - 1$
$D_1^0 + 2$	$D_2^0 - 2$	$D_3^0$	$D_4^0 + 4$	$D_5^0$

In this example,  $D_2$ ,  $D_4$  and  $D_5$  depend on  $D_1$ , while  $D_1$  and  $D_3$  are patently independent. The two dependency plots linking variation of  $D_1$  with variation of  $D_2$  and  $D_4$  are linear and their equation is given by:  $y = ax + b$ ;  $a, b \in \mathbb{R}$  (In Figure 1.a and Figure 1.b). However, in (Figure 1.c), the curve presents a polynomial relation linking variation of  $D_1$  with  $D_5$ . In this case, the dependency is non-linear but polynomial.



**Figure 1.** Types of dependency

The computed dependency data are collected and saved in a three dimension table named

$G = (g_{i,j,k})_{1 \leq i \leq n, 1 \leq j \leq m, 1 \leq k \leq \max_i k_i}$ . Each  $g_{i,j,k}$  represents the gap between the new value of  $D_j$  and  $D_j^0$  after the  $k$ th modification of  $D_i$ , where  $i, j$  and  $k$  represent the indexes of the instigating dimension, the affected one and the sampling respectively. In order to characterise dependence between dimensions in a more precise way, we convert the table  $G$  to the following 4 matrices:

**The Quantitative Dependency Matrix**, denoted by  $Q = (q_{i,j})_{1 \leq i \leq n, 1 \leq j \leq m}$  and defined by the slope of the regression line or the slope of the tangent line:

$$q_{ij} = \begin{cases} \frac{\sum_{k=1}^{k_i} z_{ik} (D_j^0 + g_{ijk} - \frac{1}{k_i} \sum_{k=1}^{k_i} (D_j^0 + g_{ijk}))}{\sum_{k=1}^{k_i} (z_{ik})^2} & (1) \\ 0, \text{ if } v_{ij} = 0 \end{cases}$$

where  $z_{ik} = (\underline{D}_i + (k-1)\sigma_i - \frac{1}{k_i} \sum_{k=1}^{k_i} (\underline{D}_i + (k-1)\sigma_i))$

and  $v_{ij}$  corresponds to the variance of  $D_j$  variation according to  $D_i$  variation.

Matrix  $Q$  measures allows comparing and classifying the different dependency relations between system's elements. In addition, qualitative dependency can be concluded from the quantitative dependency.

**The Binary Dependency Matrix** denoted by  $B = (b_{i,j})_{1 \leq i \leq n, 1 \leq j \leq m}$  and defined by:

$$b_{ij} = \begin{cases} 1 \text{ if } q_{ij} \neq 0 \\ 0 \text{ otherwise} \end{cases} \quad (2)$$

The matrix  $B$  provides a general information indicating whether a dependency relationship exist or not between two different dimensions.

**The Qualitative Dependency Matrix**  $S = (s_{i,j})_{1 \leq i \leq n, 1 \leq j \leq m}$  and defined by:

$$s_{ij} = \begin{cases} +1 \text{ if } q_{ij} > 0 \\ -1 \text{ if } q_{ij} < 0 \\ 0 \text{ otherwise} \end{cases} \quad (3)$$

This Matrix  $S$  is more specific in characterising the dependency than matrix  $B$  and shows the sign of variation of  $D_j$  when we change the value of another dimension  $D_i$ .

**The Functional Dependency Matrix**, denoted by  $F = (f_{i,j})_{1 \leq i \leq n, 1 \leq j \leq m}$  and defined by the expression of dependency function from  $D_i$  to  $D_j$  :

$$f_{ij} = \begin{cases} y = \sum_{l=0}^L x_l x^l, \text{ if } b_{ij} = 1 \\ 0 \text{ otherwise} \end{cases} \quad (4)$$

where  $L$  is the highest degree of the polynomial (if  $T$ =linear,  $L=1$ ) and  $x_l \in \mathbb{R} \forall l = 1..L$ .

This matrix contributes to a better description and characterisation of the dependency relationships which is essential a good understanding of complex system's elements interactions.

There is no pre-defined DSM which is helpful for any structured problem. Rather, DSM needs to be adapted to the kinds of elements and relations that prevail in the system in focus.

Qualitative dependency aids to predict either the increase or decrease of the affected dimension's

value after a change in instigating dimension's value. But, functional dependency offers an effective way for characterising the relationship between two dimensions and making regression, which is defined as the construction of a function from a set of data points. (For more details see [6])

## 4 Conclusion

The main goal of the current research was to suggest new approach of engineering change management to characterise the nature of dependency relationships among product components. Different matrices are proposed for change impact assessment. Research on the subject has been mostly restricted to provide qualitative and quantitative dependency values for characterising change. But authors propose functional dependency, which procures a higher analysis capability.

The contribution of this article is to use simulation to rebuild the dependency functions between components, from the geometrical point of view.

Further research might explore the selection of the sampling step chosen between two changes and investigate the optimal number of data points which allow a better and more detailed interpolation study.

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