MODELING PRODUCT CHANGE PROPAGATION DSM FOR OPTIMIZING PRODUCT’S CHANGE

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Abstract – The Managing change can be challenging due to the high levels of interdependency in concurrent engineering processes. A key activity in engineering change management is propagation analysis, which can be supported using the change prediction method (CPM). This change propagation significantly affects the development time and cost and determines the product’s success. Predicting and managing such redesign process is, thus, essential to project managers. Some prediction tools model change propagation by algorithms, whereof a subgroup is numerical. Current numerical change propagation algorithms either do not account cyclic propagation paths or are based on exhaustive searching methods. This paper presents a new matrix-calculation-based algorithm which can be applied directly to a numerical product model to analyze change propagation and support change prediction. Design Structure Matrix (DSM) models are effective approaches for analyzing and optimizing a Product Development related to design change (or redesign). In order to measure potential propagation paths, this paper presents a three-order paths DSM through identifying the influence of intermediate components to product features. Further, this paper proposes a Combined Likelihood DSM to integer, which extends the existing CPM algorithm. Finally, an industrial example is provided to illustrate the proposed models.

Keywords – Product Development, Change Propagation, Design Structure Matrix (DSM), Change Prediction Method (CPM), Project Management.

I. INTRODUCTION

In new product development (PD), engineering changes occur throughout a product life cycle and can cause severe impact on the development time, cost and quality of a product if not appropriately managed. The Change Prediction Method is concerned with prevention, early detection, effective selection, efficient implementation and continuous learning from changes [1]. Because the occurrence of changes in the design of complex products cannot be completely avoided, for instance, new requirements may be raised by the customer when the design is already released [2], a key challenge of CPM is change prediction and analysis for early detection, effective selection and efficient implementation of changes [3]. However, in common with most other methods that predict change through likelihood of propagation through dependencies, CPM has three
critical limitations: 1) subjectivity of input data [4]; 2) capability to model generic cases only [5]; and 3) lack of dynamicity of the integrated likelihood [6]. This paper has argued that all three limitations could be resolved by incorporating information from interface management into change prediction. We extend the previous CPM algorithm to identify the three-order path propagation in the product architecture, and improve the traditional method to measure the combined likelihood DSM.

II. Single Likelihood of Different Change Propagation Path

A. First Order (direct) Change Propagation

The first stage of CPM is to allow preliminary examination of direct impact on component relationships, where “change” is defined as any alteration to a product subsystem’s design. Within the Product DSM (i.e., P_DSM) the column headings show instigating sub-systems and the row headings the affected sub-systems, whose designs change as a result of change to the instigating sub-systems. Let SL(1) m,n be the single likelihood of first-order change propagation resulting from the direct impact of design change of component n on component m. So, P_DSM will indicate the direct effect of change design between components n and m, which is equal to SL(1) m,n:

\[ SL^{(1)}(m,n) = DSM(m,n) \] (1)

where m and n\{1,2,…,NC\}. As the diagonal elements of the DSM are zero, only change propagation between two different components will be considered. The numerical values in SL(1) m,n represents change experienced during the redesign process.

B. Second Order (Indirect) Change Propagation

SL(2) m,n is the single likelihood of second-order change propagation paths resulted from the indirect impact of design change of component n on component m through an intermediate component p. Only three different components are taken into account for SL(2) m,n. The likelihood of second-order (indirect) change propagation path from n to m through component k (i.e., Cn \(\rightarrow\) Ck \(\rightarrow\) Cm) is:

\[ SL^{(2)}(m,n) = DSM(p,n) \times DSM(m,p) \] (2)

where p, 1,2,...,C N and m \(\neq\) n, n \(\neq\) p , m \(\neq\) p For example, in Figure 1 (a), C4 is the intermediate component of second-order change propagation paths from C1 to C2, so SL(2)(2,1)=DSM(4,1)×DSM(2,4)=0.7×0.6.

Further, the single likelihood of all second-order change propagation paths from n to m through all possible intermediate components can be calculated as follows:

\[ SL^{(2)}(n,m) = \sum_{p} SL^{(2)}(m,n) \] (3)

Figure 1: An example of the first, second and third order change propagation

C. Third Order (Indirect) Change Propagation

represents the single likelihood of third-order change propagation paths resulted from the indirect impact of design change of component n on m through two intermediate components. Figure 1 (b) and (c) describe two situations for third-order change propagation paths, which are change propagation with cyclic path and without cyclic path respectively. SL(3) mn
For the situation of the change propagation without cyclic path (see Figure 1 (b)), the third-order (indirect) through two intermediate components p and q for the change propagation path \( C_n \rightarrow C_p \rightarrow C_q \rightarrow C_m \) can be calculated:

\[
SL_{p,q}^{(3)}(m,n) = DSM(p,n) \times DSM(p,p) \times DSM(m,q) \tag{4}
\]

where \( q \in \{1,2,\ldots,NC\} \). For example in Figure 1 (b), \( SL(4,3)(3)(2,1)= DSM(4,1) \times DSM(3,4) \times DSM(2,3) = 0.7 \times 0.8 \times 0.2 \) along path (C1, C4, C3, C2).

For the situation of the change propagation with cyclic path (see Figure 1 (c)), the third-order change propagation path would also allow the propagation path \( C_n \rightarrow C_p \rightarrow C_q \rightarrow C_m \), which includes a loop for the second component Cm. The cyclic path propagation is a propagation loop that ends with the starting component affected. The iterative problem required by cyclic path propagation is likely to involve higher coordination costs between redesign teams [7]. It can be calculated as follows:

\[
SL_{p}^{(1)}(m,n) = DSM(m,n) \times DSM(p,m) \times DSM(m,p) \tag{5}
\]

For example, Fig.7(c) shows along cyclic path (C1,C2,C4,C2) a loop in component C2. So, \( SL(4,3)(2,1)= DSM(2,1) \times DSM(4,2) \times DSM(2,4) = 0.8 \times 0.3 \times 0.6 \).

Further, the single likelihood of all third-order change propagation paths from n to m through all possible intermediate components can be calculated as follows:

\[
SL^{(3)}(m,n) = \sum_{p=1}^{NC} SL_{p}^{(3)}(m,n) + \sum_{q=1}^{NC} SL_{p}^{(3)}(m,n) \tag{6}
\]

### III. COMBINED CHANGE LIKELIHOOD

The combined change likelihood between two components is defined as the integrated probability of all possible change propagation paths across their intermediate interface (see Figure 1 (d)). We use the propagation tree shown in Figure 2, where vertical lines represent logical relationship (And), and horizontal lines represent logical relationship (Or) [8] (see Clarkson et al. 2004). The “And” function is a product of probabilities (i.e., possibility of change) and the “Or” functions as a sum of probabilities minus the product probability. The “Or” ensures that the combined likelihood will always be less than unity.

Figure 2 shows the combined likelihood from C1 to C2 through change path 1, 2 and 3 (i.e., the amount of intermediate components are 0, 1 and 2 respectively). Through analyzing the And/Or logical relationship, probabilities of change from C1 to C2 can be calculated as follows:

\[
\begin{align*}
SL^{(0)}(c_1,c_2) &= SL^{(0)}(c_2,c_1) \\
SL^{(1)}(c_1,c_2,c_3) &= SL^{(0)}(c_2,c_3) + SL^{(0)}(c_1,c_3) - SL^{(0)}(c_2,c_1) \\
SL^{(2)}(c_1,c_2,c_3,c_4) &= SL^{(1)}(c_2,c_3,c_4) + SL^{(1)}(c_1,c_3,c_4) - SL^{(1)}(c_2,c_1,c_4) \\
SL^{(3)}(c_1,c_2,c_3,c_4,c_5) &= SL^{(2)}(c_2,c_3,c_4,c_5) + SL^{(2)}(c_1,c_3,c_4,c_5) - SL^{(2)}(c_2,c_1,c_4,c_5) \\
&\vdots
\end{align*}
\]

where \( u \) and \( v \) represent the alternative potential multi-intermediate components in each “path order z” for change propagation from C1 to C2.

**Figure 2:** An example of propagation tree

For example in Figure 2, the alternative potential multi-intermediate components are \( u=C3 \) and \( v=C4 \) when . Similarly, \( u=C3,C4 \) (or \( u=C3,C2 \)) and \( v=C4,C3 \) (or \( v=C4,C2 \)) when . Probabilities of change related to the And/Or logical relationship from C1 to C2 are:
represents the single likelihood of third-order change propagation paths resulted from the indirect impact of design change of component n on m through two intermediate components. Figure 1 (b) and (c) describe two situations for third-order change propagation paths, which are change propagation with cyclic path and without cyclic path respectively.

\[ SL(3) \]

Thus, the combined change likelihood (CL) between components m and n refers to the integrated change probability in the design of component n leading to a design change in component m through all potential change propagation path z. It can be calculated as follows:

\[
CL(m,n) = SL(m,n) \cup SL(m,n) \cup SL(m,n) \\
= 1 - \prod_{z} (1 - SL(m,n)) 
\]  

(7)

IV. AN ILLUSTRATIVE EXAMPLE

An industrial example is used to verify the proposed concept and models. The original likelihood DSM is elicited from the chief designers, sales managers and project managers. SL(mn) and CL(mn) are show in Figure 3 (a) and (b) respectively.

Figure 3: Change Likelihood DSM

As the CL of the Crimper Jaws (14) is the most higher (i.e., when it is calculated as an average amount), it can be deduced that it is more likely to be changed and thus not suitable for standardization. In contrast, the Pull-Nose Device (17) has relatively lower CL than most of the other components. This suggests that the Pull-Nose Device is less likely to change and hence is a good component for standardization. System components, such as the Differential Box (3), the Dwell Gear Box (5) and the Electrical Panel (8) are the best components for standardization (CL=0).

V. CONCLUSION

This paper propose an improved CPM method to measure the combined likelihood of change in the design or redesign process and establish an efficient product development regarding multiple engineering changes.

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