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DISTRIBUTED MODELING OF COMPONENT DSM

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1 INTRODUCTION

Design Structure Matrices are useful for representing data for many different tasks across a variety of research and industry domains. As analysis routines advance and become more specific, there will be a need for more data in terms of both the types of interactions and the number of elements contained in a DSM, particularly for modeling products. This research explores the type of data contained in component Design Structure Matrices and a distributed modeling approach that reduces the effort of creating binary DSMs, facilitates a distributed modeling strategy, and aims to increase the repeatability of component DSM creation.

2 INFORMATION CONTENT OF COMPONENT DSM

The quantity of information captured in a component DSM, and therefore the effort required to create it, can be estimated by understanding the information content of the DSM. The information content of a DSM can be determined by the level of detail used along three independent axes as shown in Figure 1a (Tilstra et al. 2009). The "Element Detail" of a DSM ranges from an abstract representation of major subsystems within the product to an exhaustive list of every individual part within the system. The "Interaction Detail" of a DSM can range from a single overall interaction to a DSM containing multiple layers, each of which captures a specific type of interaction. The "Judgment Detail" of a DSM falls into three categories. At the simplest level, a binary DSM is created in which the examiners creating the DSM must make only a judgment of existence. At the next level, a judgment of significance is made in an attempt to prevent unimportant interactions from confusing the analysis. At the most detailed level, a judgment of consequence is made in which not only the significance of an interaction is recorded, but also the desirability of an interaction.

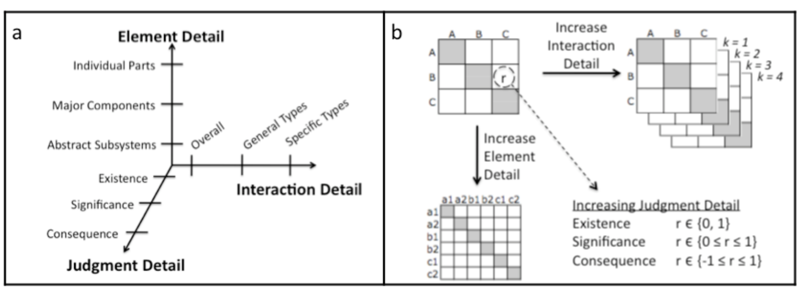

Figure 1: a) Information content space of DSM model; b) visualizing increased DSM detail

The basic format of a DSM found near the origin of the space shown in Figure 1a would be a binary DSM that uses a few abstract elements to represent complex collections of parts. While this type of DSM may be useful to obtain an overall understanding of a complex system, many researchers have found it useful to increase the quantity of detail in the DSM they use to represent a system. To study variety in product families, researchers have found it necessary to have elements for nearly every component (Alizon et al. 2007; Hsiao and Liu 2005). Pimmler and Eppinger capture four discrete types of interactions so that clustering algorithms can be based on the most important type of interaction (1994). Sosa et al. later extend this approach to five types of interactions (2003). In research on change propagation and advanced clustering algorithms, it is common to increase the information content by recording the relative significance of interactions between different pairs of elements (Eckert et al. 2004; Helmer et al. 2008; Pimmler and Eppinger 1994; Sosa et al. 2003).

The authors have proposed the use of a High Definition Design Structure Matrix (HD-DSM) that captures enough information to analyze the ability of a system's design to be evolved into future product offerings. For that purpose, concepts from research on functional modeling were combined with product architecture research to create an Interaction Basis, which defines 25 types of possible interactions between the components of a system (Tilstra et al. 2009). The elements of the HD-DSM are taken from the product's Bill of Materials (BOM), which can be large in quantity.

3 EFFORT REQUIRED TO CREATE A DSM MODEL

The amount of effort required to create a DSM model of a system can be estimated based on the number of decisions that must be made by the human examiner. For an asymmetric DSM, which allows 'one-way' dependencies to be captured, the number of cells is calculated by Equation 1, where '*n*' is the number of elements in the DSM and '*k*' is the number of interaction types. Without the aid of any software functions such as copy-and-paste or auto-fill, the time required to 'fill-in' the DSM matrix is determined by Equation 2, where '*t*' is the time allotted to determine whether or not to place a mark in each cell. This is similar to estimates found in related research (Suk Suh et al. 2008).

$$Cells = k * (n^2 - n) \quad (1)$$

$$Time\ Required = t * k * (n^2 - n) \quad (2)$$

The HD-DSM discussed above requires the examiner to determine whether or not each pair of elements interacts for each type of specified interaction. For the purpose of a rough estimation, we can assume it takes about five seconds to mentally ask and answer the question, "*Do element A and element B interact in the manner specified?*" A power screwdriver examined in related work was modeled using 33 elements. Based on Equation 2 and the above assumption, it would require over 36 hours to 'fill-in' the entire HD-DSM for this product. This estimate raises concerns for the tedium of creating such a model and also for the reliability of data collected in this manner, especially given the relative short decision time frames and the focus on redundant or ancillary interactions. The magnitude of this estimate motivates the need for a method of distributed modeling of Design Structure Matrices.

4 METHOD FOR DISTRIBUTED MODELING OF COMPONENT DSM

The method of distributed modeling for Design Structure Matrices allows the elements of the complete system to be separated into groups so that each group can be modeled independently, and then merged into a single model. The steps are as follows:

1. Determine the complete list of elements from the product BOM
2. Separate elements into rational groups (i.e. based on observations during reverse engineering)
3. Create a system DSM using a group placeholder to represent each group as a single element plus an 'External' element to capture interactions that cross the system boundary
4. Create a DSM for the elements of each group plus an 'External' element to capture interactions that cross the group boundary
5. Replace the group placeholder in the system DSM with the corresponding group DSM
6. Use the group's external interactions and the group placeholder's system interactions to determine the possible interactions of elements in the group to other system elements
7. Review the possible interactions to determine whether or not they exist in the system

After all of the groups have been merged back into the system DSM and the possible interactions have been reviewed, the examiner will have a complete DSM. The advantage of this method is that the complete DSM can be created with much less effort. If components of the system are rationally divided into groups, the modularity that exists in the system allows the examination of empty areas of the DSM to be avoided. For example, consider the simplified screwdriver in Figure 2a with seven components plus an external element. If the eight elements are considered all-at-once, there are 56 possible cells the person creating the model must examine. However, if the four components indicated are grouped together into a transmission element, the modeling effort can be divided into the system DSM and the transmission-group DSM as shown in Figure 2b. When the transmission-group DSM is merged into the system DSM, only eight cells need to be reviewed. In this simple example, the distributed modeling method only requires 48 cells to be evaluated (20 cells in the system DSM, 20 cells in the group DSM, and 8 cells that require review, '*Re*' in the merged DSM). The cells that do not require human examination are shown in gray in Figure 2c. Furthermore, this work could be distributed so that one person can create the system DSM and a different person can create the transmission group DSM.

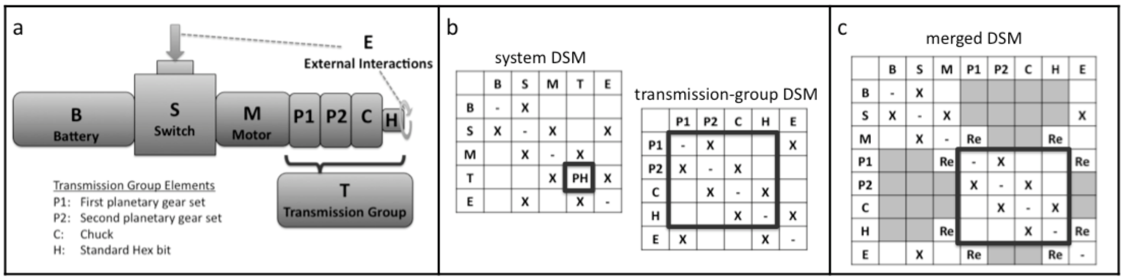

Figure 2: a) Simplified power screwdriver; b) system DSM and transmission group DSM; c) cells requiring review 'Re' with ignored cells grayed-out

This method was used to create a single DSM of the overall interaction in a Black and Decker power screwdriver. The 32 components in the screwdriver were split into six groups, each containing one to sixteen parts. The system DSM has a total of 33 elements, which includes an external element used to capture interactions that cross the product's boundary. By using the distributed method, only 508 element pairs required human examination rather than the total 1056 cells in the complete DSM.

5 ANALYSIS OF GROUP SELECTION FOR DISTRIBUTED MODELING

The success with which this method of creating a DSM will reduce human effort is analyzed by comparing the expected number of cells that will require examination when the system is separated into a number of equal size groups. Figure 3 shows the data for this analysis. The mean number of expected cell examinations required by the human is determined from 5000 randomly grouped trials at each group size based on the Black and Decker screwdriver. The mean effort required when groups are created randomly can be compared to the strategic case where groups are based on the human ordering of the BOM, the latter requiring less effort across all group sizes. This suggests that when the method of distributed modeling is used based on some rational grouping of components, the effort required to create a DSM can be greatly reduced. However, if elements are grouped without any insight into the inherent modularity in the system, using the distributed method as opposed to filling-in the complete DSM all-at-once may actually increase the amount of effort. The exception to this is for randomly created groups of two or three elements, which may reduce the amount of cells evaluated by the human examiner by over 10%. The actual DSM for the B&D screwdriver was created using six groups of varying size, which offers the most reduction in modeling effort compared to using groups of equal size. This analysis supports the conclusion that the distributed modeling of a component DSM can significantly decrease examiner effort when groups are assigned based on human intuition.

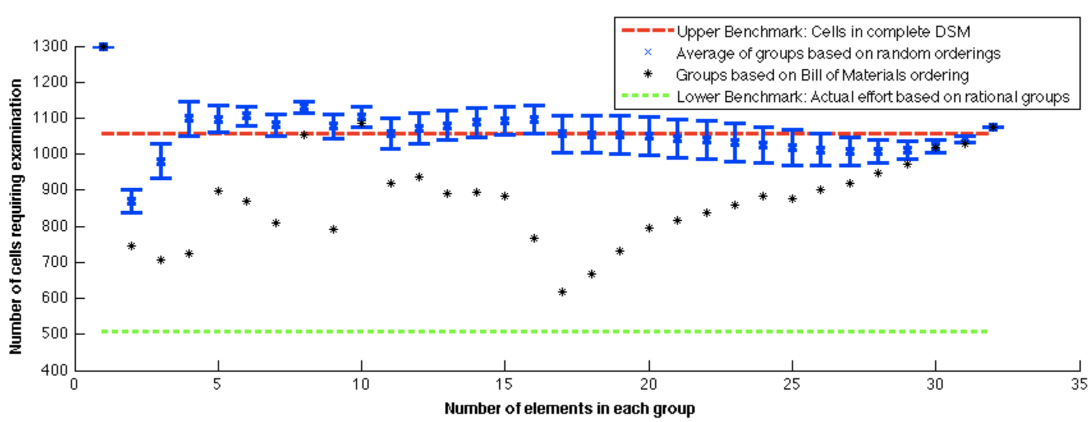

Figure 3: Modeling effort of randomly grouped elements versus groups based on human ordering

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