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Teaching DSM-based analysis based on a Case at a Start-Up

Marc Hirschka, Lucia Becerril

Laboratory for Product Development and Lightweight Design, Technical University of Munich, Germany

Abstract: Complexity Management Methods have been proven a useful methodology managing complex product architecture. However, insufficient training and lack of visibility of the advantages hinder the transfer and implementation of these methods. This paper presents a teaching case based on a real case that facilitates practical training on complexity management methods. The aim of the case is to develop an understanding of DSM and related methods among students and practitioners. The data was collected through the analysis of documents and a series of interviews within a start-up.

Keywords: Education, Case Study

1 Introduction

Design Structure Matrices or Dependency and Structure Modelling (DSM) has been proven a useful methodology for representing systems architecture (Eppinger and Browning, 2012) and managing complexity. For the past years, DSM and related methods have been applied in a broad range of industries. However, a widespread application in academia and industry is yet missing. According to Albers et al. (2013) and Becerril et al. (2017), insufficient training and lack of visibility of the advantages are major barriers to transfer and implement methods in industry.

The case method has been applied in many scientific fields as an effective learning tool since it combines what has been learned with real world problems and offers the learner sustainable learning through active involvement (Bonney, 2015; Popil, 2011). This type of knowledge transfer has been shown to increase the motivation of learners and achieve better learning success than conventional methods such as frontal instruction (Bonney, 2015; Popil, 2011). Thus, this paper presents a teaching case (TC) that facilitates hands-on training on complexity management methods. The aim of the case is to develop an understanding of DSM and related methods among students and practitioners, so that they are able to incorporate the methodology into their own projects. The TC includes DSMs, Domain Mapping Matrices (DMM) and Multiple Domain Matrices (MDM), as well as analytical methods. Moreover, during the assignment the applicability and usefulness of DSMs and related methods is demonstrated. In particular, cases offer the opportunity to demonstrate the connection between academic topics and the real world promoting the participants' understanding of the application (Bonney, 2015; Popil, 2011). Here, the participants should experience the advantages and limitations of the applied methods.

The TC reflects the results of a case study within a start-up and represents real requirements and conditions within the current development of a technical system. The data was collected through the analysis of documents and a series of interviews over the course of six months. Then, product architecture and organization's structure were modeled and analyzed.

2 Background

This chapter presents a brief introduction to DSM and related methods applied in the TC, as well as an overview on the topic of product architecture.

2.1 Product Architecture

For many years product architecture has been an important topic within product development, for instance as highlighted by Henderson and Clark (1990) and Ulrich (1995). According to Eppinger and Browning (2012, p. 7), system or product architecture (in this TC "product" and "system" are used as synonyms) is *"the structure of a system – embodied in its elements, their relationships to each other (and to the system´s environment), and the principles guiding its design and evolution – that gives rise to its functions and behaviors."*.

2.2 Design Structure Matrix (DSM)

The simplest form is the binary DSM (Yassine, 2004, p. 2). A relation between two elements is marked by "x" or "1" in the respective cell (Warfield, 1973). However, further representations are highlighted for example by Eppinger and Browning (2012, p. 5) and Clarkson et al. (2004). The DSM can help to increase understanding of the system, which results from the complex relationships between individual system components. The product architecture DSM depicts the relationships between the components of a complex system or product.

Domain Mapping Matrix (DMM)

Danilovic and Browning (2004) introduced the DMM as a complementary approach, where connections between two different domains can be visualized, e.g. components and people responsible for those components. The DMM is established as a helpful extension of DSMs in times of increasingly complex structures (Browning, 2016, p. 27). The DMM is formed by relating two different DSMs. The resulting DMM is usually rectangular (m x n), where m is the size of the first DSM and n is the size of the second DSM (Danilovic and Browning, 2007, p. 302). The analysis options for DMMs are not extensively addressed in literature so far.

Multiple Domain Matrix (MDM)

The MDM combines DSMs and DMMs in one representation. The DSMs are arranged in diagonal and the DMMs are arranged off-diagonal. In other words, it represents a DSM at a higher level of abstraction, namely between domains and not, as before, elements within a domain. Thus, a holistic overview of product development is created.

All these matrices capture, display, process, and analyze complex systems. Alone through identifying the relations and presenting the system's structure, the matrices increase system understanding and facilitate communication with others stakeholders. Analyzes allow even more in-depth knowledge about the system under consideration. (Yassine, 2004, p. 15).

2.3 Analysis Methods

Here, three analysis methods that are applied in the TC are briefly described. An overview of further analytical methods is provided in Browning (2016, p. 29).

Clustering

The most common analysis method, especially for product architecture analysis, is the clustering method (Browning, 2016, p. 30). *"Clusters represent a basis for creating modules."* (Lindemann et al., 2009, p. 227). Hence, it helps to find modules of subsystems or components which are closely linked among them and slightly linked to further modules (Yassine, 2010, p. 319). Thus, a cluster combines one or more components whereas *to cluster* means the creation of *"... a set of Clusters by means of an algorithm."* (Börjesson Frederik, 2012, p. 3). Further information is given in Sharman and Yassine (2004).

Influence Portfolio

The influence portfolio analysis enables a clear graphical representation of the components on the basis of their influence and their influenceability (Probst and Gomez, 1991, p. 14). For this purpose, the active sum and the passive sum of each component is formed (Melnikov et al., 1994, p. 279). After visualizing the DSM each row and column is summarized. In case of the row total of a component the term active sum is used. Accordingly, the term passive sum is used in case of the column total (Probst and Gomez, 1991, p. 189). These values are then entered in the influence portfolio. The x-axis corresponds to the active sum and the y-axis to the passive sum. To classify the components it is helpful to divide the influence portfolio into different areas. (Lindemann et al., 2009, p. 162).

Indirect Relations

The indirect relations analysis helps to uncover relations that exist indirectly between two components (Lindemann et al., 2009, p. 99). Especially the indirect dependencies with one intermediate component are of interest. To apply indirect relations analysis, the output matrices must be prepared correctly through data acquisition. This means that only direct relationships between components should be depicted. Hereafter, the deduction of indirect relations must take place. Effectively, a matrix multiplication is carried out. (Eichinger et al., 2006, p. 232).

3 Methodology

This section provides an overview on the methodology behind this paper. The process comprised following three phases: data collection, modelling and model verification, and TC development.

3.1 Data Collection and Modeling

Data collection, modelling and model verification was an iterative procedure. The data was collected through reviewing existing documents, inspecting physical products, and a series of interviews with domain experts. In this case, the main advantage of the interviews was that each expert could be addressed individually. In addition, questions from the expert on the method or the interviewer on detailed information or unclear relations could be answered immediately. These advantages are also mentioned by Eppinger and Browning (2012, p. 40) and Moon et al. (2015, p. 328). The interviews were conducted based on the approach by Moon et al. (2015, p. 327), whereby the following two adjustments were made. First, instead of preparing and conducting a questionnaire an interview is prepared and performed. Second, instead of conducting a consensus round survey to elucidate identified items, these items were clarified by direct discussions with the corresponding experts.

After initially brief discussions with the respective experts to obtain an overview of the system, documents were sighted, and the physical product was examined. After this phase the product could be divided into individual hardware (HW) and SW functional units (SW-FUs). Also, some spatial relationships could already be identified and documented in a first version of the spatial DSM. From the discussions and documents, preliminary information about the information flow could also be collected and illustrated in the corresponding software DSM “information flow”. In this early phase, however, the main goal was the formation of the MDM, which originally was created based on the collected information and literature research on 13 different domains. Here, the domains HW components, SW components and persons were selected to create the TC, and for further analysis within the company.

Afterwards, the relations for the connections between the selected domains were determined. In the HW and SW domains, the relations “geometrical constraints” and “information flow” were considered. In relation to the domain “Person”, the relations to be considered were “communication” (DSM) and the responsibilities towards HW and SW components (DMMs).

After the MDM and the first DSMs and DMMs were created, five domain experts were interviewed for ca. 1.5 hours each. The experts completed and verified the previously acquired HW DSM (consisting of 50 components), SW DSM (19 components), and HW-SW DMM matrices. Furthermore, during the interviews most relations among components were verified. Connections between components that could not be verified were then directly discussed with the corresponding domain experts. For all matrices created during the case study we use the binary representation and the IC convention, where the input is mapped in the columns and the output in the rows.

3.2 TC Development

The target group of the teaching case are primarily mechanical, mechatronic and electric engineers or engineering graduate students. The main requirements are an understanding of the architecture of mechatronic systems and basic knowledge of DSM and related methods, which in our case is given in a previous lecture. . Participants should experience how DSM methodology can be applied in their projects. Overall, the DSM methodology can provide a deeper and structured understanding of the interdependencies between components independently of the level of detail.

The TC was developed according to the framework by Kim et al. (2006). This framework describes the basic division of different strategies for TCs into four categories. Figure 1 shows an overview of the framework. Categories one (content), two (structure) and four (process) comprise 17 strategies that ensuring that the five core attributes (third category) are met (c.f. Kim et al., 2006, p. 869). In our contribution, the strategies highlighted in Figure 1 were applied to create a successful TC.

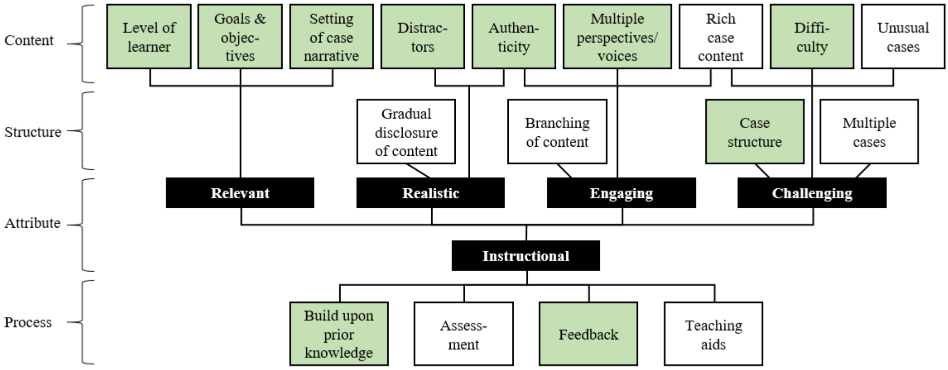

Figure 1: Conceptual framework of TC development based on Kim et al. (2006, p. 869).

The TC has been applied in three different workshops, two of them with ca. 15 mechanical engineering undergraduate and masters students each and a third occasion with ca. 20 PhD Students from the field of Systems Engineering. Thus, its applicability has been evaluated. Slight changes were made to the original TC according to the participants' feedback.

4 Teaching Case

Based on the expertise which was collected during the work within the start-up the following TC was built. The case is planned for a 3-hour workshop and the participants shall have basic knowledge on complexity management and product architecture (in the workshops we conducted this was achieved by a 1.5 hours lecture beforehand for students with engineering background.). Due to confidentiality the terms for modules and components and the names of persons have been modified.

4.1 Introduction

The start-up develops complex technical products with interconnected HW components and SW-FUs. The product is a parking spot sensor system which collects and evaluates data in real-time, thus, knowing the availability of appropriately equipped parking spots. This information can then be used, for example, by a navigation device to navigate the car driver directly towards a free parking spot. To provide this possibility, the system consists of a base STATION unit and SENSOR unit. For both HW components a SW is mandatory for a functional system. As a third component, we also consider the HW and SW employees in their respective functions in the TC.

In Figure 2 the system boundary of the considered system is pictured. The influence is displayed across the system boundaries by three different arrow types and the corresponding arrow direction. The considered domains and their relationship to each other are displayed in the MDM (Figure 3). The color of the relationship indicates whether the required DSMs and DMMs already exists (black) or must be compiled independently during the TC from additional information (red).

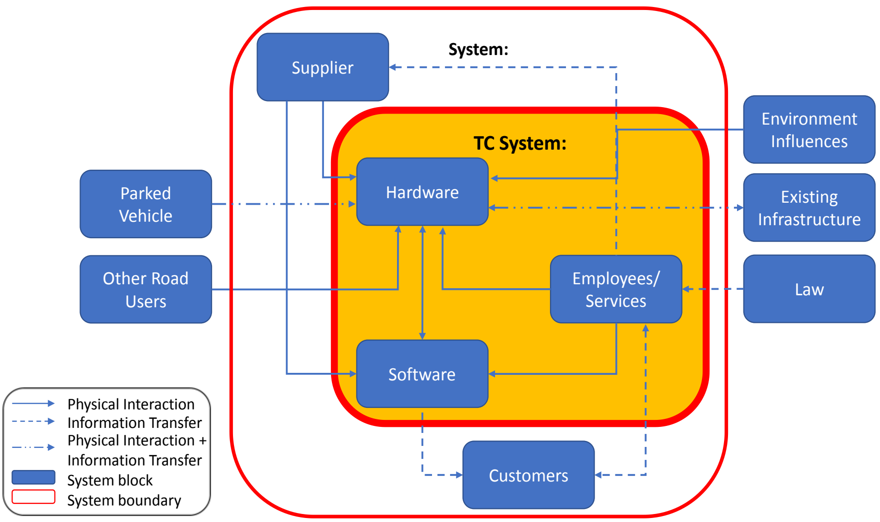

Figure 2. System boundary, the considered system (TC System) consist of HW and SW-FUs as well as employees

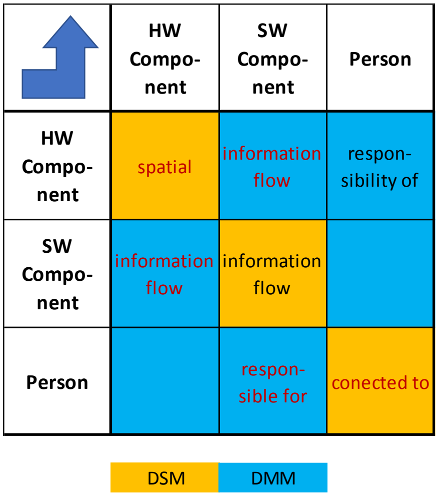

Figure 3. MDM TC with prefilled relations (black), to complete relations (red)

4.2 Preparation

A brief introduction of the situation, environment, and the expected performance as well as all necessary information to conduct the TC is presented in seven worksheets (WSs). Table 1. Contents of the individual worksheets presents the contents of the individual worksheets.

Furthermore, practical solutions are developed for three problems, which are described below. Notes on the WSs as well as practical solution sheets are intended for clarification purposes and assistance for participants and teachers. The seven WS and the three solution proposals can be obtained by email to the authors if required. In addition, a spreadsheet program is required for the analyses and best case, the program is accessible to every participant at the same time.

Table 1. Contents of the individual worksheets

WS	Content
0	Introduction text (scenario); Issues (1-3); MDM (completed for TC)
1	eMail of the Sensor-Expert to complete the HW DSM "spatial" on WS2
2	HW DSM "spatial" to be completed with information of WS1
3	SW DSM "information flow" (completed)
4	Network diagram of employees related to SW-FUs; DMM HW-Person "responsibility of" (completed)
5	Network diagram of the information flow through SENSOR and base STATION units
6	Person DSMs "connected to" to be completed

The first task is to find HW modules through clustering of the HW DSM “spatial”. Therefore, the HW DSM “spatial” must be partially self-developed.

The second objective is to identify and display the critical, active, passive and inert (Lindemann et al., 2009, p. 162) components within the SW DSM "information flow". Therefore, the active sum and passive sum of each component of the SW DSM "information flow" must be calculated and displayed in a portfolio. In addition, the threshold must be set for active, passive and critical components. Furthermore, the criticality of each component can be calculated and used to scale the size of the component within the influence portfolio.

The objective of the last task is to find dependencies between elements through indirect dependency analysis. Hence, the correct matrices must be identified, multiplied with each other, and insights must be drawn.

A summarized representation of the issues together with the questions dealt with as well as the related analysis methods and the related WSs is given in Table 2.

Table 2. Considered issues, discussed questions, analysis method, and related worksheets

Issue	Question	Analysis Method	Worksheets
1	Which HW components can be clustered?	Clustering	WS1; WS2
2	Which are the inert, passive, active, and critical components?	Influence Portfolio	WS 3
3	Which persons are connected regarding their component responsibilities?	Indirect Dependencies	WS2; WS3; WS4; WS5; WS6

4.3 Conducting the workshop

The participants are ask to envision themselves working in a tech start-up which develops parking spot sensors. They are asked to carry out a product architecture analysis of the sensor system to tackle some ongoing challenges in the start-up. For example, they should give a recommendation on who should be responsible for which HW modules. At the beginning of the workshop, the MDM in Figure 3 is given as well as all worksheets in Table 1 (WS1 – WS6). They are recommended to use a spreadsheet program and work in teams of 3-5 people.

Participants should have a basic understanding and/or receive a brief introduction to the DSM subject. In the TC, the focus lies in modelling a technical system using matrix based approaches and on applying the methods clustering, analysis of indirect dependencies and portfolio analysis (c.f. section 2). In the overview WS (WS0), the scenario and MDM (Figure 3) as well as the problems to solve are presented and the participants can work independently. However, for the instructor of the TC it might be useful to interrupt the TC between the tasks, e.g. to compare the groups result, answer questions and proceed with the same base. At the end of the workshop the questions of the participants shall be answered, the results compared and discussed. Thus, the participants shall reflect on the methods applied and their results – with the objective of increasing the understanding of the applicability of the methods and supporting the learning process.

4.4 Learnings in conducted workshops

Incorporated later, the first excersise comprises filling out a part of the DSM. This helped participants become familiar with the technical system and the modelling approach. Giving an incomplete DSM at the beginning helped balance the time necessary for the exercise with gaining understanding about the system to analyse. Furthermore using tools the participants are already familiar with, such as spreadsheets, allows the participants to focus on the excersice rather than on the tool. Depending on the level of experience of the participants, we gave hints on which analysis method to use for every question. However, experienced participants would have benefited from it as well.

5 Conclusion and Outlook

The goal of this paper is to present a realistic TC for selected complexity management methods. For this purpose, the results and experience gained during the application DSMs, DMM, MDMs and analytic methods within a start-up were used to develop a realistic and engaging TC. Based on the TC, the participants can apply these methods on a practical example gaining a deeper understanding. Moreover, the experienced insights from analysis ideally motivate the participants to apply the methodology in their daily work. To gain these benefits, the participants should receive an introduction on the topic and the basic procedures beforehand, including the analysis methods such as clustering analysis, influence portfolio analysis, and indirect relations analysis. Within the TC the topics of product architecture analysis and employee-component assignment are addressed, as well as derived relations among employees. Further applications of DSM-related methods are not included. Moreover, the three analysis methods clustering analysis, influence portfolio analysis, and indirect relations analysis are applied.

The practicality of the TC is ensured through a number of strategies as shown in Figure 1. Additionally, the TC has been evaluated in three practical applications and continuously improved. Further applications will include and a follow-up questionnaire to evaluate the TC according to the five attributes by Kim et al. (2006) and its long-term usefulness.

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Contact: Lucia Becerril, Technical University of Munich, Laboratory of Product Development and Lightweight Design, Boltzmannstr. 15, Garching bei München, Germany, lucia.becerril@tum.de, mw.tum.de/en/lpl/home