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Product development in the Swedish Automotive industry: Can design tools be viewed as decision support systems?

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Abstract

Design engineers working in the automotive industry have to take many design decisions, based on numerous diverse criteria. This results in a high workload of complex decisions. One way to reduce decision complexity and improve decisions could be to improve design tools. Decision support systems (DSSs) have been used in a managerial context to improve decisions. In this article, the authors assess whether design tools generally can be viewed as DSSs. A combination of literature review, surveys and qualitative interviews with seven design engineers was used to assess whether current design tools function as decision supports in product development. Although the specific design context needs to be considered, this study's results suggest that design tools can generally function as DSSs. In future work, the adaptability to different problem solving patterns needs further in-depth research in the form of individual studies for specific tools in specific contexts.

Keywords: engineering design; design tools; product development; automotive industry

1. Introduction

Nomenclature

DSS	Decision Support System
CAD	Computer Aided Design
PLM	Product Lifecycle Management
FEA	Finite Element Analysis
NPD	New Product Development

1.1. Background

Design engineers in the automotive industry has to consider several diverse criteria when working on their designs; everything from styling to legal requirements and production restrictions has to be taken into account before a component or system can be approved [1]. Product development methods and tools have been developed in the automotive industry to be able to realize increasingly more complex vehicles without increasing cost or quality [2] while decreasing product lifecycle time and increasing product diversity [3]. An example of the increased product complexity and diversity is the continuing trend within the automotive industry to further differentiate the use of materials in their products; this includes an increased use of established non cast-iron materials [4] [5]. All this should lead to increased demands on the design engineer in the automotive industry. When the demands on the design engineer increase, the demands on the tools used by the design engineer also increases. Some sources [6] predict a sharp increase in use of virtual design tools over physical design tools.

The increase in complexity, work load and usage of virtual design tools could be managed with a more efficient use of decision support systems (DSS), and thus reducing the risk of incorrect decisions being taken. DSSs are different tools aimed at enhancing quality in decisions. They were first introduced in the 1970s, and have since been developed in order to help mainly people in managerial positions to take informed and relevant decisions of high quality. Sprague [7] describes a number of significant characteristics of a DSS a relevant term to talk about when identifying and evaluating tools in product development.

1.2. Decision support systems

Sprague [7] proposes a number of significant characteristics of a Decision Support Systems:

1. They aim at helping users solve non-structured, underspecified problems
2. They try to combine analytical models with traditional data access
3. They focus on being easy to use by people whose expertise is not in computer systems
4. They emphasize on flexibility and adaptability, to fit different users with different problem solving patterns

Non-structured or underspecified problems can be described as problems where the initial information provided is not sufficient to solve the problem.

These four can be seen as identifying contextual, perceptual and functional characteristics of DSSs. How the four characteristics have been interpreted by the authors as contextual, perceptual or functional can be seen in table 1. The contextual characteristics have been interpreted as being a result of the industrial and contextual environment where the user is seated, the perceptual characteristics have been interpreted as affecting how pleasant the user experience is for the end user, and the functional characteristics have been interpreted as affecting what the DSS is doing behind the user interface. Correlation has been marked with an X.

Table 1 Characteristics of a DSS classified as contextual, perceptual or functional characteristics

Characteristics of a DSS	Contextual	Perceptual	Functional
Helping users solve underspecified problems	X		
Combine analytical models with traditional data access			X
Focus on being easy to use by non-computer experts		X	
Adaptive to fit different problem solving patterns	X	X	X

Sprague also describes three different technology levels for Decision Support Systems; Specific DSSs, DSS Generators and DSS Tools, with the first being the most applied (and closest to the end user) and the third being the most abstract (and far-most from the end user) [7].

1.3. Aim and purpose of study

This paper aims to investigate whether decision support system criteria can be used to evaluate design tools in automotive product development. The purpose is to review how design engineers view their tools, and if the previously not used mental model of design tools as Decision Support Systems could be applied.

2. Research design

2.1. Research questions

The authors try to answer the following research question:

- Are there design tools that can be viewed as decision support systems that are currently being used by design engineers in the Swedish automotive industry?

In order to answer this, the following four questions were being formulated:

- Do design engineers encounter underspecified problems on a regular basis?
- Are there design tools that combine analytical models with traditional data access?
- Are design engineers computer experts?
- Are there design tools that encourage different problem solving patterns?

2.2. Data collection

In order to answer the formulated questions, an interview study was performed alongside a literature study to complement the data collection as can be seen in figure 1.

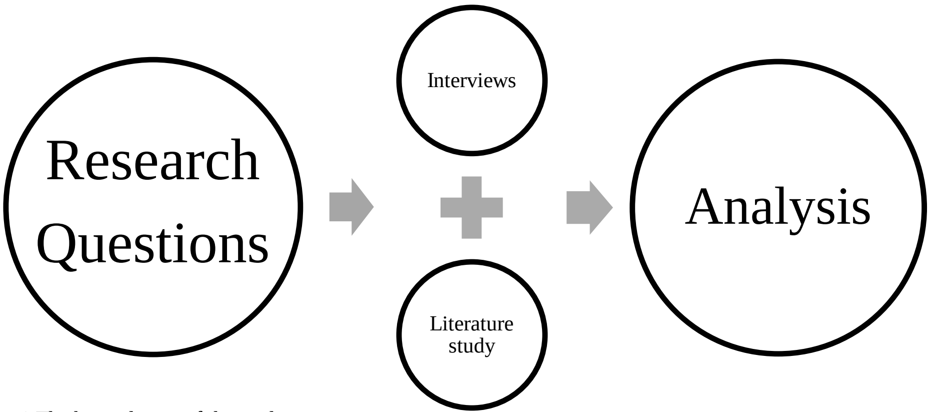

Figure 1 The basic design of the study

2.2.1. Interviews

Semi-structured telephone interviews with four engineers in or with very recent (less than one year absence) experience from the Swedish automotive industry were performed. Respondents were convenience sampled.

The respondents were asked to describe their position in the product development process, their work tasks and the design tools that they are using regularly. Their answers regarding tasks and position in the product development process were mapped against the Ulrich & Eppinger [8] product development model (more thoroughly described in 3.1), and respondents not involved in physical design (phases 2-4 in the model) were excluded from the study. One respondent was excluded in this stage due to not having had their main work tasks and deliverables within phases 2-4 in the Ulrich & Eppinger model.

All respondents included in the study were at the moment of interview working in the Swedish automotive industry, albeit in different companies and under different circumstances. According to Hecker [9], at least parts of the motor vehicle manufacturing industry (of which automotive is a part) could be classified as a high technology industry. Production volumes are high, and in 2014 the median time from design start to launch was estimated to drop to 18 months worldwide [6].

The interviews were performed in order to investigate what design engineers working in the automotive industry today views the topics of decisions and design tools. The answers have been analyzed in order to formalize precise answers to the proposed research questions.

An additional interview was performed with a CAD software expert, who has 20 years of experience in teaching in CAD software at university level and have continuously been examining the five big CAD systems (PTC CAD systems, Catia, Inventor, SolidWorks and NX). This was done to investigate one research question that was not answered in the interview study with current design engineers. This interview will be referred to as the expert interview.

2.2.2. Literature study

A literature study was performed in order to validate the interview findings. This study focused on design and product development literature, investigating the context for the design engineers and theory behind some commonly used design tools. The literature study has also aided in creating designing the interviews.

2.3. Delimitations and assumptions

This paper has been limited to only investigate digital tools used by design engineers in the industry. Only design engineers in the automotive industry have been interviewed, which means that the result cannot necessarily be generalized outside this industrial sector. Likewise, only design engineers working in Swedish companies have been participating in the study, which means that the result cannot necessarily be generalized globally. This paper has been focused on specific design tools, and responses regarding very common office tools as email clients and the Microsoft Office suite have been excluded from the results. The authors have only focused on Specific DSSs, since the respondents in the interview study have been viewed as end users. In this paper, the terms “Design”, “Engineering Design”, “Product Development” and “New Product Development” are used as synonyms.

3. Theory

3.1. Product development and design engineering theory

Ulrich & Eppinger [8] describes an arbitrary new product development (NPD) model to consist of 1) planning, 2) concept development, 3) system-level design, 4) detail design, 5) testing and refinement and 6) production ramp-up, as can be seen in figure 2.

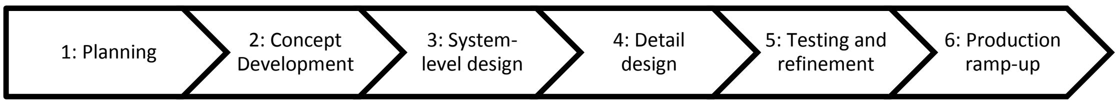

Figure 2 The product development process, adapted from Ulrich & Eppinger [8]

3.1.1. The characteristics of a design problem

Ullman [10] describes a design problem as defined by two features: the problem being ill-defined and that there is no correct answer. Ill-defined is described as *the problem statement does not give all the information needed to find the solution* [10]. Hurst [11] notes that there are no objectively absolute answers in engineering design, since design parameters are very likely to contradict each other and pose the need for compromises. Cross [12] proposes that ill-defined problems, which he proclaims design problems to be, have the following characteristics:

- There is no definitive formulation of the problem
- Any problem formulation may embody inconsistencies
- Formulations of the problem are solution-dependent
- Proposing solutions is a means of understanding the problem
- There is no definitive solution to the problem

3.2. Design tools

A tool is *a means that, in a predefined and systematic way, facilitates the user's work towards a desired outcome* [13]. This means that a design tool should be something, be it software, an object or else, that aids the user to design a product in a predefined and systematic way. There are many types of design tools, from abstract tools (as FMEA sheets or QFD analyses) to concrete and visual tools (as CAD software or physical prototypes).

3.2.1. Design tool classification

Design tools and practices can be classified according to their main functionality in the product development process with regards to information processing [14]:

- Translation
- Focused information assembly
- Communication acceleration
- Productivity enhancement
- Analytical enhancement
- Management control

When looking at typical and unique design engineer tasks, three classes of design tools and practices becomes more interesting than others: tools for focused assembly of information, tools for enhancing productivity and tools for enhancing analytical abilities.

3.2.1.1. Focused information assembly

Assembling information or knowledge early in the NPD process can improve the quality of design decisions [14]. DfMA approaches could be seen as a way of assembling diverse information early in the process.

3.2.1.2. Productivity enhancement

Productivity enhancement could be described as *the use of tools or practices that improve the speed or reliability with which one or more routine activities of new product development takes place* [14]. Examples of productivity enhancement methods could be drawing templates or early CAE testing.

3.2.1.3. Analytical enhancement

Analytical enhancement seeks to help the designer analyze tasks, cases or situations that are too complex for most humans to reliably process [14]. Modern FEA tools are very good examples of analytical enhancement in the NPD process.

3.2.2. Design engineers' requirements on design tools

According to Lindahl [13] there are four major requirements from design engineers on the tools they are using:

- They must be easy to use
- They must enable the designer to fulfill product requirements
- They must reduce the risk that activities in the development phase are forgotten
- They must reduce the time it takes to solve the task

If these four requirements are not met, the tools are not being used. Lindahl emphasizes on the first and last requirement, proposing that these two are the most important requirements to fulfill when designing a new tool.

3.3. Problem solving patterns in design

Amadori [15] and Tarkian [16] have shown that CAD software can provide many different solving patterns for design, by enabling different levels of automation in the CAD models. Edward de Bono's proposed idea of "Six Thinking Hats" [17] [18] have been applied to product development processes [19] with results indicating that this method of "forcing" people to use different ways of thought could work for problem solving in design.

4. Interview data

In this section, the interview data is presented. First, an overview is shown and further on elaborations from the interview respondents are presented.

4.1. Interviews with design engineers

In the following section, the findings from the interviews with design engineers will be presented.

4.1.1. Interview data overview

In table 2, an interview data overview is presented.

Table 2 Interview data from semi-structured interviews with design engineers

Interview topics	Design Engineer 1	Design Engineer 2	Design Engineer 3
Years of work experience as a design engineer	Three and a half year	Two years	Less than a year
Responsibilities in product development process according to Ulrich & Eppinger	3-4	2-3-4	2-3-4
Taking decisions individually	Yes	Yes	Yes
Taking decisions in team	Yes	Yes	Yes
Handling underspecified, underdefined or ill-defined problems on a regular basis	Yes	Yes	Yes
Usage of tools to assemble and integrate information	Yes	No	Yes
Usage of tools to enhance own or others' productivity	Yes	Yes	Maybe (more methodologies than tools)
Usage of tools to enhance analytical abilities	Yes	Yes	No
Level of expertise in computer systems	Moderate to good	Moderate	Moderate to low

4.1.2. Respondents on taking decisions

Design Engineer 1 (DE_1) says that there is no clear difference between the decisions taken individually and in the team, but that the decisions taken in the team feel more solid. Some decisions are clearly not able to take on your own, as those affecting others. “I rarely take decisions that affect others without consulting them” says DE_1.

Design Engineer 2 (DE_2) says that most decisions are taken in collaboration with someone else, regardless of topic. DE_2 emphasizes on the communication between people regarding decisions.

Design Engineer 3 (DE_3) has design responsibility for some parts, but still communicates with superiors regarding larger revisions sometimes.

4.1.3. Respondents on underspecified, underdefined or ill-defined problems

DE_1 responded that conflicting information is a daily occurrence, and believes that this could be due to the vast number of components in the end product, and that the compromise between different component qualities and performance between components creates this environment.

All three respondents acknowledged handling underspecified, underdefined or ill-defined problems on a regular basis.

4.1.4. Respondents on design tools

All respondents mentioned working in some sort of CAD software, along with a PLM solution. That ties in with all respondents describing some sort of model representation of a physical product as their deliverable or part of their deliverable.

DE_1 mentioned creating their own tools in shape of automatic or parametrically driven CAD models (see [15] or [16] for further explanations on parametric CAD models), saying that they always try to create their own tools for speeding up reoccurring, noncreative work.

DE_1 also described an automated system for collision analysis in larger component systems, but said that they are only using it as a “safety net”. DE_2 mentioned a similar system, saying that they get feedback from this system when the main CAD model is updated (every night).

4.2. Expert interview

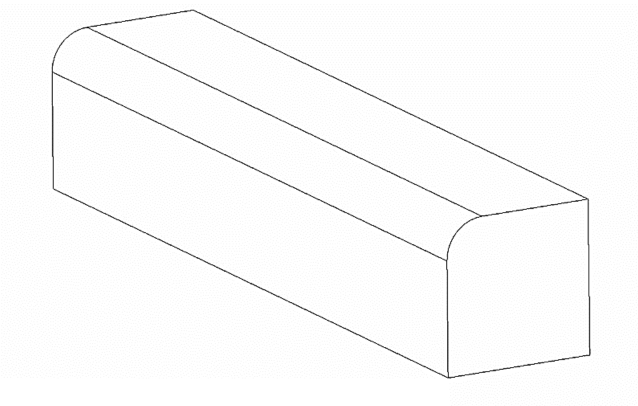

Figure 3 Example geometry for interview

The respondent was asked to identify and describe possible ways of achieving an example geometry (figure 3), and found at least four common operating procedures:

1. Creating a square extrusion, sketching the corner by hand and removing the geometry by extruding a “negative” geometry
2. Creating a square extrusion and using the predefined functionality of rounding a corner (if such functionality is available in the software)
3. Sketching a square with one rounded corner and then extruding this geometry
4. Creating a square extrusion, converting the solid to surfaces and modifying these to create the rounded corner

Depending on the circumstances that created the need, all these four ways of creating the geometry could be the best or only solution. The first three methods are commonly used by students in CAD design courses depending on the specific task and the experience of the students. In the experience of the respondent, the third solution is the most common for students without prior experience in CAD software.

5. Results

The respondents all acknowledged working with ill-defined, non-structured or underspecified problems on a regular or even daily basis. One of the respondents discussed that this could be due to the vast number of components in the system, and that the compromise between different component qualities could be seen as a basic underspecified problem.

DE_1 and DE_3 mentioned CAD and PLM software as tools for assembling and integrating information, along with internal webpages with component libraries. Different templates were identified as tools for enhancing productivity, both CAD models and methodology templates. One respondent specifically said that they are often trying to create useful tools for them self, to enhance productivity and make the workload easier.

DE_1 and DE_2 also mentioned automated envelope analysis tools, which were designed to identify possible design faults easier. These tools were identified as enhancing analytical abilities (one respondent). A possible scenario to use the envelope tool was described to be when two movable or retractable systems (such as hinges) are situated in close proximity to each other, and where there could be difficulties for the engineers to analyze the both movements with regards to each other without analytical help.

The same two respondents described collision analysis tools, but were not agreeing on how to label the tools. One respondent identified the tools as enhancing productivity, while the other preferred to label the tools as enhancing analytical abilities.

DE_1 and DE_2 identified themselves as having moderate to good computer knowledge, while DE_3 described their knowledge as moderate to low. All three respondents were at the moment of the interviews working as design engineers, and have background in mechanical engineering or product development.

In the expert interview, it was found that CAD software commonly supports multiple ways of creating geometries, and that these different ways of creating a geometry are (to different extent) commonly used by students in fields related to engineering design.

6. Analysis

Since existing theory suggest that design problems are in its core ill-defined and several references describes ill-defined as underspecified with regards to information, and all respondents acknowledge handling ill-defined problems on a regular basis, the contextual characteristic of underspecified problems seems to be fulfilled in the automotive industry.

The respondents describe themselves as having moderate to good knowledge, or even low knowledge, but never expert knowledge, in computer systems. They are also all within four years of graduating with mechanical engineering or product development degrees, so it could be assumed that they are not dedicated computer experts but engineers with basic computer skills. This point to a conclusion that the perceptual characteristic of tools being designed for people whose expertise is not in computer systems fits for design tools as well as DSSs. This is also supported by the findings of Lindahl [13], who emphasizes on the usability of design tools for them to be implemented in industry.

7. Discussion

The method of convenience sampling interview respondents creates a risk for sampling bias. In table 2 it can be seen that the general work experience in the respondents is quite low, less than five years for all respondents. While this limits the possibility to generalize the result, for this focused research question the sample was considered adequate. In a possible continuation of this study, the sampling should be addressed both in size and representation of the whole workforce.

During the interviews, it became apparent that some design engineers are not always sure whether they have the authority to take a decision themselves, or if they need authorization further up in the organization. While this seems trivial at first sight, it does create a possibility for either delays or erroneous decisions in the product development process. This should be examined further.

For this study, the authors limited the study to specific DSSs, but during the interviews some respondents indicated that they are themselves creating tools to help them in their daily work. This could mean that the design engineers are not solely end users of DSSs, but also DSS builders. At the moment, this view on the design engineer has not been included in the study. If it is common for design engineers to build their own tools, they could be included in tool development from many viewpoints. This should be examined further.

A future possible study stemming from this work is an evaluation of how current design tools fulfills the automotive industry with regards to decisions in material selection and integrating product and production development.

8. Conclusions

Since design engineers are not computer experts, and work with ill-defined or underspecified problems on a regular basis, the context is there for analyzing design tools as decision support systems. The authors have identified design tools that do combine analytical models with traditional data, in different parts of a design engineers' work. Some design tools have features enabling different problem solving patterns.

The conclusion of the study is that there are design tools that could be viewed as DSSs, but that a general conclusion whether all design tools could be viewed as DSSs or not cannot be done. Instead, individual evaluations of design tools in certain contexts need to be performed.

9. Further studies

Further studies include validating this result on a larger population, preferably with a more diverse experience and in several fields of industry. For a more applicable result, it would be interesting to focus further studies on a specific set of tools, for example tools for material selection. It could also be of contribution to investigate the view of the design engineer as a DSS builder, since it seems like some design engineers create their own tools for decision support. Studying how a new individual in an organization learns how decisions are made in that specific context could help evaluate current design tools, and propose new development paths for a new generation of design tools that further help engineers with design decisions.

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