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DEPENDENCIES IN CONCEPT DECISIONS IN COMPLEX PRODUCT DEVELOPMENT

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1. Introduction

The purpose of the study presented in this paper is to identify dependencies in product concept decisions taking into consideration social aspects, decision structures and technology. This will serve as a base to defining improvements in the concept decision process. The results are based on a retrospective interview study regarding a case in the automotive industry. Empirical data was gathered through interviews and supplemented by reviews of internal documentation such as gate reports and design reviews.
The case, within a car project, was subject to major internal attention and experiences from the case were considered to be of great importance for the company. The chosen concept solution for the case had to be reworked, which meant that extra time and effort and additional money was needed to solve the problems, before product launch.
The company in question has a documented and mandatory product development process with defined instructions, process maps and a basic chain of command. In spite of the operational support, the company still suffers from a certain amount of rework based on incorrect concept decisions. Results from the empirical study show that there are both formal and informal factors that affect the concept decisions.

1.1 Concept evaluation and selection process

The activities in the concept phase aim to generate several concept alternatives, evaluate the alternatives based on all relevant prerequisites and finally select the concept that will be developed in the project. The selection process is complicated and it is not always possible to fulfil all customer requirements initially set since they could be contradictory. The concept evaluation and selection process is essential for the project's prospect to succeed. It is important to focus on these early activities since the main part of the product and manufacturing cost is committed during concept design. More than 70% are committed at the end of the concept phase [Ullman, 1997] (Figure 1).

1.2 Design methods for concept selection

There are several suggestions for supporting the evaluation and selection processes e.g. simulation and optimisation [Gavel, 2007] and evaluation matrices [Pugh, 1990]. Evaluation methods are however, not frequently used in industry [Janhager et al., 2002].
Baker and Albaum [1986] have listed normative evaluation models that have been commonly used for product screening in four general categories. *Ranking models* compare one product idea against others according to a specified set of evaluation criteria – the highest ranked product is selected. *Scoring models* use criteria considered to be critical to a product's performance. Each idea is evaluated using

these criteria and those that exceed a minimum acceptable score are selected. *Economic models* are based on deterministic or probabilistic payoffs, profits, ROI (return on investment) etc. *Optimisation models* are based on selecting the product which maximises certain mathematical functions identified. Baker and Albaum also test the effectiveness of alternative decision models.

1. *Conjunctive models* accept or reject decisions based on whether the concept passes or fails *all* of the evaluation criteria.
2. *Disjunctive models* accept a product that exceeds specified levels on one or few criteria, regardless of scores on the others.
3. *Lexicographic models* rank the evaluation criteria, comparing individual criteria separately until one idea is deemed to be superior to the others.
4. *Linear compensatory models* multiply a product's score on a criterion using the weighting on each criterion and then adding all evaluation criteria.

Deciding which model to use may vary with the type of product involved, the nature of the company, its existing product line, markets and goals.

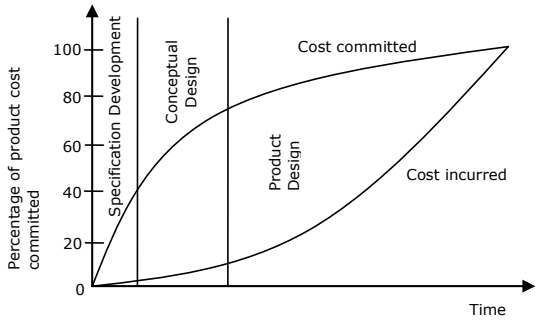

Figure 1. Manufacturing cost commitment during design, Ullman [1997]

1.3 Decision-making in product development

The different models for concept selection are developed in order to support decisions, however they seldom treat the intrinsic dependencies between technological and human factors in the actual decision-making. From the perspective of product development important research highlights different support for decision-making. For example, Badke-Schaub and Gehrlicher [2003] defined five *patterns* of decision-making in product development:

1. Leaps - fragmented process, no clear common goal in the group and deficient decisions that had to be revised.
2. Loops - reiterations, long time period for decision and poor results.
3. Cycles - reiterations of partial sequences of process steps, long decision process, controlled muddling-through.
4. Sequences - step-by-step, rational, rapid decision process, progress in problem solving.
5. Meta-processes - moderator guides, progress in problem solving.

The step-sequential patterns (cycles, sequences and meta-processes) are more successful than the two other patterns (leaps and loops). However, leaps and loops thus should be avoided, 47% of the decisions observed in the study were identified as belonging to these two patterns.

1.4 Fixation and attachment to concepts

A phenomenon that may affect the concept selection is *fixation* of, for example, a certain idea. During a concept stage it is important to consider all relevant alternative solutions and a challenge can be to evaluate the different alternatives in an objective way. Jansson and Smith [1991] provide an example of the existence of *design fixation*. During tests a group was shown a design sample and the group

seemed to be 'fixated' by this. The solutions produced by the group contained many more features from the design sample than solutions produced by a group that was not shown the design sample. According to Jansson and Smith, a fixation could affect the conceptual design negatively if it prevents the designer from considering all the relevant knowledge and experience that should be taken into account.
Another kind of *fixation* is attachments to early solutions and concepts [Cross, 2006]. Designers tend to stick to their principal solutions for as long as possible, even if problems appear during the detailed stages of development.

2. The design of the interviews

Qualitative research interviews were carried out using a semi-structured form. Open questions were used to obtain the interviewees opinions and experiences regarding their roles and the decisions made in the car project studied. Nine people were interviewed and the respondents were chosen from the project group, design project managers, top management, middle management and computational engineers. The respondents were given the task to reconstruct the course of events of the early project phases. A timeline was used during the interviews, to support the respondents in order to refer to the same time frame. The interviews were recorded and transcribed by the author.
The author created a chronological picture based on the interview responses and sketches made during the interviews as well as documentation from design reviews and gate reports. The purpose of these sketches was to gain a better understanding of the chronological order of causes and effects of different activities. A list of case-specific problems was identified from the total transcribed material. The chronological picture of the course of events and the list of problems in the earlier phases of the car project studied, were presented to and verified by the respondents. During the verification session, some additional data was added. Analysis through categorizing the transcribed material was performed aiming to find what was influencing the concept decision.
The author is currently employed at this automotive company and has experience from working in projects at the company. Therefore, the organisation and the common working procedures were well-known to the author. To some extent, this also includes previous knowledge about the case studied.

3. Results: course of events

Below, a number of important situations that occurred during the car project studied follow. The situations did in fact all influence the concept decision process in different ways, sometimes in a direct way and others by indirect means. The concept decision is the moment in the project when the solutions to be detailed developed, and further on industrialized, are decided. Technology, cost and timing are reviewed on the principal solution presented. The main emphasis of the case is on one specific engineering department that solely works with mechanical systems and the case focuses on one sub-system of the product within one specific product attribute.
The company studied (one car brand) is referred to as Company Alfa. The other collaboration company (another car brand owned by the same automotive group) is referred to as Company Beta. In this paper, the platform collaboration between Company Alfa and Company Beta is called Platform Sigma. For the purposes of this paper, the car project focused on is called Project A. A second car project at Company Alfa is called Project B.

3.1 New functional organisation

During the initial stages of Project A there was a comprehensive functional reorganisation at Company Alfa. This reorganisation resulted in the centre of power being moved from the projects to the functions in the matrix organisation. New roles, chain of command and decisions forums were introduced. The new functional organisation was considered to have too many reporting levels and the areas of responsibility were perceived as too small. Due to the reorganisation a number of new managers were appointed on several levels at the same time. The respondents working in Project A at the time experienced that the functional organisation lost focus on the technical issues and the development projects. Thus, it took too long for the organisation to be up and running and return to a

proper working pace again. Due to the matrix organisation (functional and project) combined with the platform collaboration as well as an additional internal brand structure (Company Alfa's projects were clustered within Platform Sigma) the project members sometimes had four different chains of command: line, project, brand and platform which resulted in the project members spending a lot of time on status reporting instead of focusing on the technical problems.

3.2 New platform

Project A was to develop the first product on a new platform (Platform Sigma). The collaboration in Platform Sigma was not the first experienced by Company Alfa, however, the collaboration in Platform Sigma was decided to be designed in a different way than its predecessor. This resulted in a new platform organisation and a new kind of work split between the participating companies. Platform Sigma and the new working procedures were developed in parallel with the first car project on the new platform (Project A). Extensive discussions, sometimes political, took place between the participating companies and much energy was spent on these and therefore distracted attention from the technical discussions and the concept decisions. Those respondents with experience from the preceding platform collaboration considered their experience from the previous platform collaboration as valuable but disregarded and that these experiences were not taken into consideration in the new platform collaboration. For instance, they knew how challenging it could be to achieve high performing cross-brand teams but not enough preparatory work was done to attain high performing teams at the start of Platform Sigma.
A challenge for platform development is to consider all future products that are going to use the common platform parts. In this case, the platform parts were developed together with Project A. The knowledge regarding the coming car projects was very limited due to the fact that it had not yet been decided what cars should be included in Platform Sigma. In this specific case, it had been overlooked that the second car project on the platform (Project B) should determine the dimensions of the technical platform system. This resulted in the production tools for Platform Sigma's parts being ordered based only on the analysis for Project A not considering computations and virtual analyses for Project B. The computations for Project B were planned later on. This resulted in the platform tools ordered not fulfilling the demands on the platform and some tools for carry-over parts developed in Project A eventually had to be replaced.

3.3 New requirements and prerequisites

In the automotive industry the products are judged and rated by several external, objective, world-wide rating institutes with different areas of interest. The results and ratings presented by the external institutes are often reported in media and therefore affect the sales of vehicles. The automotive companies were aware of an imminent new testing method at an external rating institute in a relevant attribute area. Project A was the company's first car project that had to comply with the new attribute requirements. For the concept phase of Project A (when the requirements should be filtered down from complete vehicle level to system level), the new testing method had preliminarily been decided but it was still undergoing changes. The new testing method was published by the external institute at a time when the concept decisions were made and the concept phase was already completed, which gave rise to late project input that affected the concept solutions. Improvements in the sub-system of the product had to be implemented based on this input.

3.4 Experiences from previous projects

In Project A there were examples of experiences affecting the project both positively and negatively. Computations were done early in the project and improvements to the system were defined and implemented following regular work methods in the company. During the detailed development, experiences from a previous car project at the company was gained regarding system level requirements. When this new information was implemented, it was revealed that the status of the systems in Project A was much poorer than previously known.

More lessons were learned by the time of the physical verification. The results from the physical tests were not as expected. Experiences from earlier projects showed that computations in this area were "conservative" i.e. they indicated poorer results in the computational environment than was expected in the physical testing. When the results from the physical tests were analysed, it was revealed that the computations were more accurate than had been expected. The "positive marginal" expected was no longer a reality. Improvements between computations and physical testing was, among other things, due to a rise in the level of the accuracy of the computational method.

3.5 Reporting problems

The status is reported all the way through a car project, both in a structured way in gate reports and design reviews but also through informal information channels. Early in the project there was a "gut feeling" on the operational level that the attribute status was not good enough. However, the respondents felt that it was not acceptable to judge according to gut feeling anymore. They felt that a cultural change had taken place in the organisation, meaning a change in the working climate resulting in a decreased openness and team spirit. Actions on the attribute status were not taken until very late. The respondents highlighted several contributing factors to this indistinct handling:

- new appointments to several management positions meant that some informal information paths no longer applied. This contributed to information not reaching higher management in the same way as before
- preceding car projects were in their final phase and required a lot of attention. Those problems were much more obvious than the fuzzy start in Platform Sigma
- many problems were reported early in Project A. The specific, severe, problem studied in this case, did not get the attention required. One reason for this was too many problems reported in the gates, which made it difficult to sort out the major issues.

3.6 Unplanned events in the project context

A car project runs for several years and the project context cannot be frozen. External events that demand attention and require extra engineering efforts will occur. During Project A, the exterior product styling was reworked since the product was not perceived as being sufficiently attractive for the market. The decision was made internally in Company Alfa but externally to Project A. The redesign decision was made after the concept phase was completed.

Another event that required many additional engineering hours was a radical change to another major sub-system (with interface to the sub-system focused in the study). The decision for this change was made by the company group, which was deeply questioned at the engineering department and it generated many discussions, some of which were referred to in the interviews as more political than technical. The change of the sub-system resulted in a different kind of performance that did not concur with experiences from earlier projects at Company Alfa and initiated even more technical changes. The consequences also meant that many task forces were in progress for a long period, which drained resources.

These two extensive changes resulted in a total project replan. The planned start of production was adjusted due to the extra engineering hours needed. A vigorous effort was made in order to master the situation. All project members involved made a phenomenal job to improve the technical solutions before the start of production. The team succeeded and the product was launched on time (according to the updated project plan) and met the established requirements.

4. Discussion

The case studied was a rather special case for Company Alfa including major reworking. Project A was perceived as being extremely unclear and bothersome. In the studied case several factors that influenced the project and the concept decisions were identified. There are the structural issues as the functional organisation, chain of command and the specified product requirements. There are also other factors that strongly influence work on the concept: team work, working climate, leadership culture, individual competence and driving forces which cannot be related to the formal structure of

the company. The study reveals how important informal factors are in the management of product development decisions.

Table 1. Examples of formal and informal factors

FORMAL FACTORS	INFORMAL FACTORS
• Organisation structure	• Team work
• Chain of command	• Working climate
• Product requirement	• Leadership culture

According to the respondents, the reorganisation resulted in a more fragmented organisation. An increasing number of reporting levels and smaller areas of responsibility than previously existed. The management system was referred to as being overstaffed and the reporting meetings were more a control activity instead of an opportunity to obtain support for the project members. No one was willing to take the responsibility to solve the overall problem since the problem covered many areas of responsibility. One respondent commented that there were too many controlling levels, which decreased the commitment of the coworkers. This contributed to the respondents feeling that management played a passive role.
In general, a car project is initiated with a request where customer attributes demands are defined together with the desirable product attribute targets. In this case, some of the targets were not defined until after the concept phase (the official testing method was published by the external rating institute following the end of the concept phase). The uncertainty of not having the product targets in order meant a decline in clarity during the concept phase and this made it more difficult to choose the proper technical solution since goals were also unclear.

4.1 Supporting working methods

Structural support for the product development process is available in the company; instructions, support methods and many others were used during the project. However, according to the respondents, no concept evaluation method was used in this car project. This can be compared to Janhager et al. [2002] where only 15% of the companies in the study use an evaluation method.
The results from the interviews did not provide an exact answer on how the concept decision was made. It was not one major decision from one specific meeting but rather a chain of minor decisions made in different forums. This might be one reason as to why no evaluation method was used. Another reason might be that when concepts are chosen in the projects there are several concept decisions that have to be made in parallel and the time available does not allow defined evaluation methods to be used. An evaluation method used by the concept team would have made it possible for the team to gather skilled and experienced people which most likely would have brought up problems that were only discovered later in the development process. The team would thereby have discovered if important information was uncertain or perhaps even missing. An important effect from method application is the gathering of competence with a systematic approach to work through a specific issue. From comparisons of different literature regarding evaluation methods, the authors believe that a fruitful method would be a Linear Compensatory Model [Baker and Albaum, 1986] where the team starts by weighting the criteria. Then they may consider the known reliability of the responses from analyses performed.
Since the final concept decision did not arise from one specific meeting, it is difficult to see any clear pattern in the decisions made but it seems similar to the leaps pattern [Badke-Schaub and Gehrlicher, 2001]. The concept solution was a result from incremental decision-making where the goal of the decision was not sufficiently clear from the start. The leaps pattern is characterised by a fragmented process, no clear common goals and deficient decisions that had to be revised which all appear in the case studied. By redirecting the participants' attention to the decision process including the priorities and common goals, they should be able to reflect on their own thinking processes to prevent leaps and loops patterns.

4.2 Fixation in the concept phase

As previously mentioned, there are also factors that can be more difficult to express concretely; team work, competence and cultural issues. The interviewees identified that the concept work was too detailed in too early stages. Some members of Project A felt that they did not receive any positive response for new ideas in the concept phase when they discussed matters with the design engineers. "The concept phase was not creative," and there were insufficient concept discussions. This can be referred to as *design fixation* and *attachment to concepts* where the design engineers find it troublesome to accept new design influences at the expense of design they already have [Jansson & Smith, 1991 and Cross, 2006].

To be able to handle work in a concept phase, i.e. evaluating different solutions, the co-workers need a particular mindset and a specific way of thinking to be able to deal with parallel concept solutions and to reduce the fixation and attachment to early solutions [Jansson and Smith, 1991 and Cross, 2006]. It seems relevant to assume that fixation in designing concepts can also apply to decision-making for concept solutions. When analysing Toyota, Morgan and Liker [2006] identify that management should prevent decisions from being made too quickly, but once a decision is made, it should only be change if absolutely necessary.

4.3 Using gut feelings

It was not acceptable to report problems purely based on gut feelings anymore, according to the respondents. They referred to a radical change in the leadership culture that had an effect on the working climate. Consequently, problems were known at an operational level in the early stages of Project A (based on gut feelings, not be documented sufficiently factual) but the information did not reach top level management in the same way as it had done before the cultural change.

Similarly, the respondents referred to the fragmented functional organisation. They lacked support from the management on overall issues. No one was prepared to take responsibility for the overall issues that were not within their areas of responsibility. The respondents felt exposed with the knowledge they were carrying since much of the informal information based on gut feelings had vanished and the support was lacking for the overall issues. No one was prepared to listen nor to help them. There was too much focus on the individual responsibility at the expense of the team's overall task. According to the respondents, the team spirit in the company disappeared during this period.

4.4 Utilising experiences

Technical knowledge can be identified when designing technical solutions including assessing technical solutions that someone else has designed. In Project A improvements were done in another technical area that was not considered to affect the technical area focused on in this study. When the detailed development was executed, it appeared that the optimisation for one attribute area affected other areas negatively. Experiences, a part of competence, can affect current work both positively or negatively. As mentioned during the course of events, the expected positive margin between the computations and the physical testing was no longer relevant. This experience was therefore affecting negatively.

4.5 Ability to start over

Project managers on different levels need to know how to report the problems and project status in both formal and informal ways. They should also know how to listen and screen information and find the essence in the massive flow of information to identify what is important. In the case studied it was illustrated that project managers needed a strategy (based on experience, courage, risk-taking etc.) for when to cease fine-tuning an existing solution and when to go back to the drawing board.

4.6 Organisational stress

In the verification session with the respondents, looking at the total course of events, it was stated that it was a tough time working in the project with all the major changes ongoing; new organisation, new platform collaboration and changed cultural values. The respondents referred to it as an organisational

stress, which involved coworkers trying to find out what to do, how to do it, and together with whom? The organisational stress resulted in coworkers not having the time nor the energy to reflect on what should be done early in the project. Therefore it can be argued that during large changes in an organisation, one should pay extra attention to the operations that risk loss of focus when employees are occupied by other events.

5. Conclusions and further work

In order to understand the dependencies in and to improve the work with concept decisions in a complex context, the current paper argues that one has to consider different factors, both formal and informal. Conclusions can be drawn that both formal and informal factors influence the concept decision in the studied case. Factors that are traditionally not regarded in concept decisions e.g. leadership and organisational issues but also more traditional factors e.g. technical data have to be taken into consideration when dealing with the concept decision process. This study is a part of a research project that aims to improve the concept decision process at an automotive company. Further work will focus on identifying the influencing factors in the concept decision process and to identify how the factors are connected as well as their individual impact on the process. Studies will be performed in other companies to strengthen the empirical base. Improvement proposals will be developed on how to strengthen positive factors and how to control the obstructing factors.

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