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THE DECISION PROCESS IN SET-BASED CONCURRENT ENGINEERING- AN INDUSTRIAL CASE STUDY

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1. Introduction

Decision-making and selection of different design alternatives is a central activity in the product development process and an area of considerable interest in the design society. On an abstract level the aim of decision methods is to create a representation of customers', users' and other stakeholders' interests in the evolving product in order to select the most promising alternatives to spend resources on. Several systematic methods have been created to support engineering decision-making, but so far none of them is considered the silver bullet of selection principles. Current selection methods are often using multiple product properties as input parameters. These properties are processed in order to create a score or rank that hopefully represents the "best" candidates at the present phase of development. Even though state-of-the-art methods are used, many difficulties remain and the nature of design is often to make decisions under uncertainty. One reason for this is that the amount of possible design options is almost endless and consequently it is not feasible to generate and test all options in order to get complete knowledge of the design space. Therefore most methods use the knowledge at the current level of refinement to forecast the characteristics of future designs in order to select the most promising one.

Unfortunately, this is a Catch-22 situation: it is not possible to make decisions based on the performance and characteristics of a particular design until the degree of detail is sufficiently high, but these details are not possible to design unless numerous decisions are made. Many decision supporting methods have also another important drawback: In spite of a sound logical or empirical foundation, important input to the decision process is subjective and based on personal preferences. It is often expressed in the form of estimates of customer requirements or ranking the importance of different product properties.

The decision process of Set-Based Concurrent Engineering, SBCE, offers a different approach and this exploratory paper compares set-based decisions to Pugh's method of controlled convergence. The purpose is to investigate if the set-based decision process renders different results compared to the traditional Pugh matrix selection in an industrial case study involving professional engineers.

2. Related research

Decision making is a popular field of research in operations management, computer science, healthcare and other areas. In short, the purpose of decision methods is to assist humans in complex decision situations. These situations are frequently occurring in the design process when designers must choose between different alternative future solutions.

This paper is delimited to the comparison between the decision process of Set-Based Concurrent Engineering [Ward 1994] and Pugh's method for controlled convergence [Pugh 1996]. The choice of Pugh's method as a datum for the comparison relies on many points: is easy to use and well known through textbooks and research. It is also the method used by the industrial partner and the participating engineers had no experience of other structured practices. The choice of set-based selection principles is less straight forward since it is not well known in industry [Raudberget 2010] and is characterised by a slow decision process [Ward, 1995], a feature usually considered having a negative impact on the performance of a development process.

The subject of design evaluation is challenging by the reason that many decisions are based on the knowledge and beliefs at the current level of refinement for predicting the performance of future designs. However, the set-based approach is different, using the mechanism of excluding solutions that are incompatible with the main core of the product [Ward, 1994]. In practice, this is a simple rejection of solutions that are proven unfeasible according to relevant criteria at the current state of development [Raudberget 2010]. Commonly, the approach is known as the exclusion method, and is also suggested as a decision method in early phases of product development [Roozenburg, 1995].

2.1 Pugh and Kesselring's matrix selection methods

Assume that selection involves a set of *m* alternatives to be evaluated. Each alternative has the attributes or properties *i* that are to be evaluated with respect to a set of *j* evaluation criteria. Pugh's method uses three criteria: better "+", same "S" or worse "-" than a datum, the reference solution. Sometimes each attribute is also given a weight factor or importance k, an approach suggested by Kesselring [Kesselring, 1951]. The evaluation process is a comparison in pairs of the individual attributes of each solution to the corresponding attributes of the datum. The result is often summarized into a score, a single number representing the quality of each design. Ideally, the best alternative corresponds to the best scores. However, this is not the way Pugh intended the method to be used. The "+" and "-" are not to be summarised since their strengths and characters are different. Instead, the matrix provides a base for discussion on design evaluation rather than pointing out the best solution. The matrix shows the strengths and weaknesses of different concepts and serves as a guideline to which concepts to improve in an iterative process.

Before any evaluation can begin, regardless of the use of the matrix, attributes must be clarified, an appropriate strong datum selected and sometimes weight factors calculated. The process is not straight-forward since it is relying on human judgment rather than hard facts. One issue is how to obtain the properties of a future technical system without designing, building or simulating it first. The attributes/properties of several unfinished designs must be predicted, often related to the domain of customer requirements, specifications, legal obligations, manufacturing- and other constraints. In order to limit the work load, a two stage selection can be used: The first stage is a coarse evaluation supposed to eliminate a vast amount of low quality design, followed a more precise prediction of the attributes of the remaining solutions with subsequent Pugh's matrix selection. In spite of the issues mentioned above, Pugh's method is used by the company.

2.2 The decision and specification management process of Set-Based Concurrent Engineering

In Pugh's method, the selection and approval of specific product solutions is done early when the knowledge of the product is not complete. The set-based approach is somewhat the opposite of this; Instead of selecting the most promising solutions, the impossible or least feasible are rejected [Raudberget, 2010]. The logical robustness of the rejection approach is appealing since the consequences of incorrect choices are rather small. If a designer is using a selection method promoting the second best solution as the candidate for industrialization instead of the best it is much more critical than excluding the second worst solution instead of the worst.

Mathematically, the nature of selection and rejection are different, coming from the fact that they are complementary. Any selection method focuses on maximizing what designers desire; a rejection is based on what they do not want or what is not possible at the time of rejection. Contrary to the selection of alternatives, the elimination of alternatives can be confidently done from incomplete information, which is one of the strengths of the SBCE decision process. However, in order for the set-based evaluations to be relevant, all decisions must be based on facts, not optimistic forecasts or beliefs [Kennedy 2008]. This is emphasized by Ward who describes the importance of seeking tradeoffs between different alternatives and the corresponding need for knowledge [Ward 2007].

The management of specifications is also an important feature of SBCE, aiming at an optimal system design rather than an optimization of components under fixed constraints. Initially, SBCE specifications are not fixed numbers but rather a range of upper and lower limits representing design specifications [Ward, 1994]. The approach eliminates the need for a complete specification at the start of project. The SBCE decision method does not include a pre-determined number of steps and can be used regardless of the state of development or maturity of the technical system. The convergence of the evolving design is controlled by adding more constraints and narrowing the specifications.

2.3 The origin of Set-Based Concurrent Engineering

The term “Set-Based Concurrent Engineering” was coined by Ward et. al. [Ward, 1994] as opposed to the traditional “Point-based” development methodology, characterized by an early selection and approval of one “best” specific solution. In the product development context, a “set” denotes a palette of different solutions to a specific function or problem and can be seen as a family of design proposals. Ward found SBCE in use at Toyota Motor Corporation displaying a different way of organizing and carrying out development compared to the phase-gate approach of the western world. Different authors have given their own interpretation of SBCE, where the evolvement into “Lean Product Development” is worth mentioning. However this paper follows Sobek’s initial formulation of the three principles of SBCE [Sobek, 1999]:

1. Map the design space:	Define feasible regions, explore trade-offs by designing multiple alternatives and communicate sets of possibilities.
2. Integrate by intersection:	Look for intersections of feasible sets, impose minimum constraint and seek conceptual robustness.
3. Establish feasibility before commitment:	Narrow sets gradually while increasing detail, stay within sets once committed and control by managing uncertainty at process gates.

The first principle implies a wide search for possible solutions [Sobek 1999]. Initially SBCE do not take other department’s needs or opinions into account as opposed to the concurrent engineering practice, where constraints from different departments are considered in the beginning of development. The second principle integrates the different solutions by eliminating those that are not compatible with the main body of solutions using a minimum set of constraints. The last principle implies developing solutions that matches the other sets while not violating current specifications.

Convergence of the design process is supported by the second and third principle through the elimination of solutions by repeatedly tightening the specifications and looking for intersections. Specifications are gradually narrowed down to a fixed point, but are flexible during the process, allowing engineers to compromise on different aspects. When information to enable elimination is not readily available, the designers evaluate, build or simulate the remaining solutions to gain knowledge of the different alternatives. The set of possible solutions gradually decreases through the sequence of elimination and information retrieval until only one remains. Although it seems circumstantial, studies have shown that the SBCE decision process is effective [Ward, 1995]. One reason for this may be that choosing alternatives requires detailed knowledge of all different alternatives while the elimination of alternatives requires only partial information.

3. Case study: Sensor system design

The sensor system case study was a part of a three year research project aimed at describing the effects of SBCE in industry [Raudberget, 2010]. The project was a joint-venture between six Swedish companies, the School of Engineering in Jönköping and the SWEREA IVF research institute. The collection of information was actively done by participation in meetings or workshops and the first step was to investigate current development practices. Through semi-structured interviews and by studies of documents it was concluded that practice was well-aligned with the Point-based methodology: after an innovative period the company quickly evaluates the alternatives and selects a system design for further development. In order to enable set-based work, the teams were allowed to bypass the ordinary development processes whenever appropriate. An outline for the implementation of SBCE was developed based on the company's development practice, findings in literature and the researchers' previous experiences of development projects. The researchers also introduced the companies to tools and methods for different tasks in the project and engineers were given papers and literature on SBCE.

The company in this study is a medium sized mass producing subcontractor with in-house production and design capabilities. The products are designed to customer specifications around a core technology containing mechanical and electronic systems. Their development process is well defined with a detailed phase- gate model, documents, checklists and instructions for some standard tasks. The study describes how the set-based decision process was used and how it affected the design. It is also a comparison between set-based decisions and the company's current "best practice" design selection. In the study, design evaluation was done both by the set-based evaluation and a traditional design matrix method.

3.1 Project set-up

The project goal was to develop a robust, versatile and cost efficient sensor system giving a reliable binary detection of the state of a safety device. The safety device is needed to avoid legal complications and the intention was that this technical solution would become the standard solution for new projects. Currently, there are four different sensor systems in production, all having different issues such as robustness, comfort, assembly cost or component cost. A new improved sensor would provide benefits with regards to both cost and quality since the performance of the safety device system often is one of the major problems at the end of projects. The key success factor of the project was to design a sensor system where the characteristics of the output signal easily could be controlled, in combination with smooth and silent operation. The initial project deliverable was a functional prototype demonstrating the sensor system, along with detailed specifications. The sensor system was to be designed with set-based principles. Methods from the current development process were also used, serving as a reference for "best practice".

The first principle of SBCE is "Mapping the design space". This is a natural start for most engineers and not different from the standard practice. Literature describes that in SBCE, the different sets of design proposals are generated in its functional context [Sobek 1999]; mechanics suggest a set of mechanical solutions and electronics design sets of electronic solutions et cetera. In this project the generation of solutions was done in cross- functional, creative sessions with representatives from mechanics-, electronics- and production departments. The result was 28 "new", i.e. untested, principles to measure the position of a component, besides the four currently used principles. Some of the new principles were standard sensors or components that could be integrated into a sensor, other principles were abstract and required significant development in order to provide measurement. One example is the principle of removing the need for a sensor by calculating the position of the component via physical effects rather than by a separate measuring component.

To enable comparison between the outcome from traditional and set-based decisions, the first steps of sensor evaluation was repeated twice on the same set of solutions. In order to not bias the result, the Pugh method was used before the application of set-based elimination. This order is motivated by the lack of significant knowledge build-up during the first run of the Pugh matrix, allowing subsequent set-based eliminations of the same data under comparable circumstances.

The sequence of the two different development paths are illustrated by figure 1, both starting with the definition of a set of design solutions. In the current point-based methodology, the first screening and elimination of solutions is done by applying the engineer's experiences and thereby removing the main part of the most spectacular solutions, followed by a matrix selection of the best or a few best solutions for further development. If more than one alternative is selected, the process of development and selection is repeated, otherwise only development remains. In the study, no development occurred before the set-based evaluations were applied to the sensor principles.

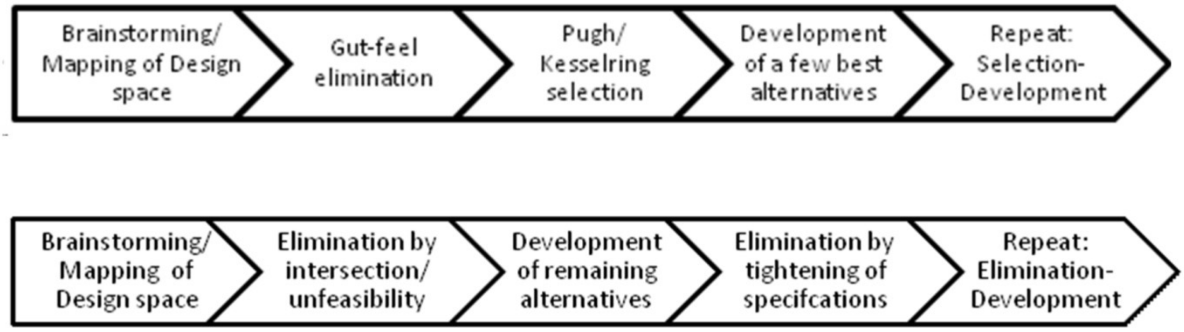

Figure 1. The current Point-based process and the Set-based process

3.2 The current decision process

Through studies of the current company practice it was found that development was consistent with the point-based process: the starting point is the generation of ideas, individually, in functional- or cross functional groups. After this an alternative is usually selected. If a project is considered complicated or particularly risky, more than one alternative is further investigated or developed. However the common practice is to develop only one alternative after selection of solutions. The pilot project was given enough time and resources for a thorough search for new ideas and for evaluation. There were also resources for subsequent refining of a few parallel alternatives.

Through discussions on evaluation methods it was discovered that the company did not have a well defined process for design decisions in early stages of development. Therefore it was decided to make a “best practice” evaluation including all methods normally used. In this way no aspects of evaluation were skipped which was important in order to be able to compare the results to the set-based evaluation.

The first round of evaluations were a screening of the immature concepts, a subjective “gut-feel” process where the designers estimated both the technical potential and the risk of failure for each alternative on a ten grade scale. All alternatives where the risk was greater than the potential were eliminated and the result was a stop of most unfamiliar solutions. Also three solutions were eliminated since they did not fall into the scope of the project. The result was an elimination of 20 solutions.

The second evaluation of the remaining alternatives was made by two matrix evaluations. The intention of Pugh’s method is a repeated selection-development, but in the current set-up, only one round of evaluation was planned before restart and initiation of the set-based elimination. A careful selection of the datum is important [Pugh 1996], and the optical gate sensor was selected for this purpose. In the firm’s application of Pugh’s method, the engineers summarised the “+” and the “-” and interpreted the highest score as the best solutions. This approach is not supported by Pugh! At this first run, a few attributes on robustness and accuracy for some sensors were hard to evaluate so the engineers put a question mark indicating a need for more information in order to confidently evaluate this technology. At this point there was no doubt about the performance of the four sensor principles used in current products.

To catch important aspects of the different solutions, the effect of weight factors on the evaluation was investigated by the Kesselring matrix. The most important properties were previously defined in a QFD where the customer requirements were transformed into technical criteria. The weights or importance for each attribute was calculated by a comparison in pairs of all attributes answering questions of the type “is hysteresis more important than detection time?”

The evaluation matrix in table 1 shows the result of Pugh and Kesselring evaluations. Note that the three highest scores of both methods are equivalent regardless of the weight factors, but the ranking order is different.

Table 1. Scores from Pugh and Kesselring evaluations, (where the "0" denotes "same" instead of the regular "S"). The three highest scores as well as uncertain properties are shaded in grey. Note that all of the currently used solutions (bold types) received a very low score

No	Properties	Pugh	Kesselring weight	***Optical detection***	***Hall sensor***	***Reed sensor***	***Mechanical switch***	Capacitive sensor	Inductive sensor	Back bias	Permeability	Solenoid inductivity	Short circuit	Plunger as potentiometer	Multiple coils
1	Resolution of detection		18	***R***	0	0	-1	0	0	-1	-1	-1	-1	-1	0
2	Hysteresis		19	***E***	0	0	-1	0	0	0	0	0	-1	-1	1
3	Detection time		5	***F***	0	0	0	-1	-1	-1	-1	-1	0	-1	-1
4	Climate, temperature		21	***E***	-1	-1	0	0	0	-1	-1	-1	1	1	-1
5	Corrosion,		11	***R***	0	0	-1	0	0	0	0	0	-1	-1	0
6	Fluid, dust		16	***E***	1	1	1	0	0	1	1	1	0	0	1
7	Electronic environment		20	***N***	0	0	1	-1	-1	0	0	1	0	0	1
8	Magnetic field		23	***C***	-1	-1	0	0	-1	-1	-1	-1	0	0	-1
9	Mechanical abuse		5	***E***	1	1	0	1	1	0	1	1	1	1	1
10	Durability (no. of cycles, ageing)		17		0	0	-1	0	0	0	0	0	-1	-1	0
11	Piece to piece variation		16		-1	-1	-1	1	1	1	1	1	0	1	1
12	Diagnosis		10		-1	-1	-1	0	0	0	0	0	-1	0	1
13	Positioning		9		1	1	0	1	1	1	1	1	1	0	1
14	Adjustment of switch point		12		0	0	0	1	1	1	1	1	0	1	1
15	Signal processing		3		0	1	1	-1	-1	-1	-1	-1	1	-1	-1
16	Total component price		15		1	1	0	1	1	0	1	1	1	1	0
17	Level of internal refinement		2		0	0	0	1	1	0	0	1	1	0	1
18	Initial investment cost		5		0	0	0	-1	-1	-1	-1	-1	-1	0	-1
19	Development cost		3		0	0	1	-1	-1	-1	-1	-1	-1	1	-1
20	Noise		12		0	0	-1	0	0	1	1	1	0	0	1
21	Robust appearance		1		0	0	0	-1	-1	0	1	1	0	0	-1
22	Simple to assemble		10		0	0	0	1	1	1	1	1	1	0	1
23	Poka yoke		15		-1	-1	1	0	0	-1	1	1	1	0	1
24	Known manufacturing technology		7		0	0	1	-1	-1	-1	0	1	0	-1	0
	Pugh concept score:			0	-1	0	-1	0	-1	-3	3	6	1	-1	5
	Kesselring concept score:			0	-40	-37	-39	25	2	-25	33	62	-3	-8	85

The technologies that needed further investigation are marked in grey and both the capacitive sensor and inductive sensor could be the best alternatives if the uncertainties worked in their favour. At this point, it was an agreement between the selection methods on which technologies were the most promising. The selection process was halted here but the next step would be to further investigate the capacitive- and inductive sensors in order to see if the ranking changes, followed by a choice of a best or a few best alternatives for preliminary design/selection of components.

3.3 Set-based decision process

After completing the traditional decision matrixes the evaluation process started over again with the initial 32 solutions. The elimination was done according to SBCE principle 2 and 3 starting with readily available information. Initially, simple criteria such as "technology readiness" was used, where the availability of commercial “off the shelf” components were enough to keep the solution in the set. Solutions that were out of the project scope were also eliminated as well as principles that could not fulfill the functions needed. One example is principles for relative measurements where there is no guarantee of finding the absolute home positions or identifying the difference between obstructed and home positions. Components incompatible with other parts of the system were also eliminated: A strain gauge solution requires a redesign of another component and is therefore not compatible with the set.

Further elimination was done stepwise by acquiring knowledge of the solutions, as opposed to the “gut-feel” process used in the company standard decision process. The first criteria concerned sensor functions and could be found in data sheets. Properties such as detection distance and precision were investigated and any component fulfilling the initial broad specifications was kept in the set. Subsequent elimination was done by adding more constraints such as the need for special voltages, external processor requirements or detector size. Solutions that needed further investigation were kept in the set but marked with a question mark “?” and these were assigned to specific engineers to check. After some time no more data could be found by desk-top studies and in order to get relevant information a test rig was developed.

4. Comparison between Set-based evaluation and Pugh’s method

The results of the different evaluations can be found in table 2 where a question mark “?” symbolizes a need for more information. The first two columns represent the screening of the current point-based process. The third column shows the solutions selected by Pugh’s method where the top-3 solutions are highlighted. The last columns show the elimination by set-based principles. At this point the traditional selection had eliminated all of the four current technologies whereas the set-bases method kept them in the set. The question marks from the Pugh matrix concerned new principles, and under normal circumstances, development would have started with one of these. The set-based elimination still had 14 solutions to investigate.

4.1 Test results

So far, no practical design work had occurred and the next step of the firm´s development process is the selection of a concept for development. In Pugh’s method, the existing sensors passed without questions raised on their properties but the set-based method required the four existing solutions to go through the same procedure of evaluation as the others. When no more relevant knowledge of sensor performance could be found to eliminate confidently more concepts, information was achieved through testing.

The purpose of the test rig was to enable measurement of different aspects of sensor performance such as switching tolerances in different temperatures. The tests started with the sensors currently in production with surprising results revealing that the designers only had shallow knowledge of the important factors affecting the technologies in use. These had less precision and repeatability than expected which can be clarified by two examples: Even though mechanical switches were considered well-known technology it was discovered that these were very sensitive magnetic sensors, it was found that some types were sensitive not only to the strength of the magnetic field, but also to small changes in other parameters. Variations in temperature, the orientation and polarization of the field and also the physical size of the magnets affected the function. The findings showed that the practice of using a sensor from one product and a magnet from another is unfeasible, even though the currently used design parameters, the strength of the magnetic field and physical distance, are within accepted tolerances.

The result of the tests was that instead of developing new sensors, knowledge of the current technical solutions was created. This knowledge is critical for making decisions in practical design work and therefore a compilation of design guidelines was created. Following the guidelines prevents designs from coming too close to its technical limits and the firm expects this to give improvements on cost and quality in the manufacturing process. The cost and the time spent on designing the test rig were also estimated being magnitudes lower than developing and validating new solutions.

Table 2. Grey fields represent eliminated sensor principles. *C* indicates current technology

Concept	Not within scope	Eliminated by Gut-feel	Not Top 3 in Selection matrix		Eliminated by availability, compatibility	Eliminated by preliminary performance	Eliminated by more constraints	Remarks
Activation current		x				?	?	
Angular sensor		x				x		
Back bias			x			?	?	
Cam curve		x				x		
Capacitive sensor			?			?	x	
Conductive carbon		x			x			
Conductive fluid		x			x			
Current and voltage through solenoid		x				?	?	
External permeability			top3			?	?	
Fiber optics		x				?	?	
Guided auxiliary locking device	x				x			
Hall sensors			x			?	?	*C*
Inductive sensor system			?			?	x	
Laser		x			x			
Mechanical switch			x			?	?	*C*
Multiple coils			top3			?	?	
Multiple coils externally		x					x	
Optical gate (Ref)			x			?	?	*C*
Optical reflection		x				?	?	
Piezo element		x				x		
Pneumatic/hydraulic pressure		x			x			
Pressure/force gauge/film		x			?	x		
Programmed magnet	x				x			
Pulse train counter	x				x			
Radioactivity		x			x			
Reed sensors			x			?	?	*C*
Short circuit induced by solenoid			x			?	?	
Solenoid inductivity			?+ top3			?	?	
Solenoid permeability		x				?	?	
Ultrasonic gauge		x				x		
Strain gauge		x			x			
The plunger as a potentiometer			x			?	x	

to the direction of the switching force, especially in combination with certain common accessories. These affected both the absolute force needed for operation and the switch-point tolerances. For

5. Conclusions

The objective for the development project was to find a better sensor and in that sense it never reached its initial goals. The main reason for the problems with the sensor units was not a need for new sensor principles but a lack of understanding of the important parameters controlling the designs. This lack of knowledge was not found through the current development process, which was unable to pinpoint the root causes of the existing sensor problems.

The purpose of this exploratory study was to investigate if the set-based decision process renders different results compared to the traditional Pugh matrix selection, and in this case it did. The decision matrixes promoted the development of new sensors and the set-based process showed that the main problem was a lack of knowledge of the important design parameters in current designs. However, the engineers did not apply Pugh's method in the intended way! Contrary to Pugh's intentions, the results of each evaluation were added into scores, and the highest scores were interpreted as the best solutions. The engineers' misinterpretation of Pugh's method is not a coincidence, and the author has found several questionable descriptions of the method in well-known textbooks, for example "The Mechanical Design Process" [Ullman, 2002].

Judging only by the decision matrix, it is unlikely that the results would have been different if Pugh's method had been applied correctly. The results in this case are comparable: the three highest scores and the largest number of "+" fully correspond. Even though the process was halted after the first evaluation, none of the currently used principles came out strong enough to be further developed. There were question marks in the decision matrix, indicating a need for more information, but not for the current sensors. Further investigation of these areas would not lead to a promotion of current technology.

Pugh's description of the method is also contradictive. It intends to select the right *concept* for future development, and Pugh stresses that the method is valid only for comparisons between alternatives at the same level of abstraction. A comparison between existing sensors and future concepts is therefore meaningless. Nevertheless, Pugh states that "If a design or designs already exist for the product area under consideration, these must be included in the matrix and always form a useful first datum choice" [Pugh, 1996]. This statement implies that the existing sensors should be included in the process, and hence invalidating the rule demanding all concepts to be developed to the same state of maturity.

Contrary to Pugh´s method, the set-based decision process does not require the different solutions to be equally detailed. Only the aspects subject to evaluation needs to be investigated. This makes it possible to make feasible comparisons between existing and mature solutions side by side.

The intention of Pugh's method is to allow a repeated selection-development of the best concepts, allowing "design principles to emerge visibly in a context" through several iterations [Pugh, 1996]. One drawback is that the process relies heavily on judgement and tacit knowledge and can therefore be manipulated by strong individuals, promoting their favourite solution for selection. This psychological factor may also be the reason why none of the currently used solutions received a high score, and the evaluation may have been affected by the knowledge of the shortcomings of these solutions. However, the engineers were not convinced that the selection results were correct and the fact that current technologies have been used for many years both by the company and its competitors provides evidence of their merits.

A rejection of concepts may seem like a discouraging approach, but has many advantages. The method can hardly promote a favourite or be controlled by emotions, as long as it is based on facts of what is not possible. The elimination of alternatives can be confidently done from incomplete information and the approach allows the more critical decisions to be made at the end of the process, when the knowledge of different alternatives is at its largest. The approach promotes facts before judgement, and in the study, the engineers found an important knowledge gap about current sensors when searching for facts. The disadvantage of the method is that it uses slightly more man-hours.

It would be desirable to also evaluate other decision methods, but it's worth remembering that the purpose of the methods is to help engineers to decide which alternatives are most likely to succeed. Whether it was optimal or not to cure the problems of current technology instead of developing new sensors we must conclude that the results are different. In this case, the firm preferred the alternatives promoted by the set-based decisions.

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