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BALANCING PROPERTIES WHILE SYNTHESISING A PRODUCT CONCEPT – A METHOD HIGHLIGHTING SYNERGIES

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1 Introduction

Balancing, here, refers to the management of properties of a product concept in order to provide user value in a cost-efficient way. In industrial product development, balancing of properties and performance/cost ratio is a challenging task [1]. Indeed, daily work practice can be seen as central for stepwise development of a balanced solution. At the same time, many decisions are made at detail level, with limited consideration of overall solutions and overall performance/cost ratio. For instance, many sub-systems or component solutions are developed – or changed – considering only their isolated context, thus not considering interrelationships in an overall product context. Consequently, there is an evident risk that sub-solutions in interaction may produce property conflicts or generally poor property balance. Specifically, late changes at detail level, often aimed to cut costs or adjust product offer, may result in an overall concept solution still holding features or performance levels that are not utilised (which is not cost-effective).

Many design methods proposed in literature should, basically, support balancing activities; for instance Value Analysis [2], or Pugh's concept evaluation and enhancement method [3]. However, these methods often involve the consideration of several parallel concept alternatives, which is very resource-consuming and difficult to manage in large industrial projects. In addition, they do not explicitly consider interrelationships in the concept. The DSM technique [4] involves extensive analysis of interrelationships. On the other hand, it requires a lot of information to be available initially, which is usually not the case in concept development activities, and it does not consider overall product value. When applied in development of complex products, DSM also requires vast information analysis and interpretation. Hansen [5] proposes an approach to tackle the issue of simultaneous synthesis and optimisation of product concepts, basically more suited to this study's scope. With a basis in function-oriented decomposition of the system, the design of the product is seen as a sequence of design steps, where each step includes both synthesis and analysis. However, while Hansen presents a phenomenon model of the design process, in turn having the aim to develop supportive computer tools, the focus here is to provide a practical work procedure for cross-functional teams. Ziv-Av and Reich [6] also propose a design method for generating optimal concepts, with the intention to provide a simple yet powerful support. The method, SOS (Subjective Objective System), works by decomposing a complex problem into smaller sub-problems. In the overall sense the method is intended to output the optimal concept given the customer objectives, the company context, and the available constraints. SOS involves linear programming and mathematical optimisation, meaning that evaluations made are relatively precise, but also that the model has to be fed with detailed engineering data. Appropriately, Weiss and Gilboa [7] strive to minimise the effort for synthesising product concepts while creating optimal combinations of solution principles. In addition, they emphasise the need for an approach that is practically applicable when information is scarce. In presenting their method, DSO (Direct Synthesis Optimisation), they also consider compatibility between solutions as an important aspect, even though they don't actually focus on utilising synergies between them.

Reflecting the industrial and theoretical background, the idea of this study is to support early balancing of properties, when synthesising a product concept, and while utilising synergies across different sub-systems or components. Since the method aims to be applied in the early concept phase, it must involve the use of vague information and engineering assessment. A further notion is that the approach should constitute an efficient and practical decision support in industrial, cross-functional teams.

The study's scope and objectives are basically problem-oriented and reflect the industrial situation referred to, including the associated empirical findings [1], [8]. Methodological support is developed by complementing well-known design methods while having the industrial situation in mind (Section 2). Special effort is made to provide a design methodology that is easy to learn and apply, supports co-operation, and facilitates learning in the development team [9]. The resulting synthesis and balancing methodology is applied in a running product development project within a Swedish car manufacturer, in order to demonstrate, explore, and evaluate its practical effects in use (Section 4). The application also means that the acceptance of the method is tested (cf. "verification by acceptance", [10]). To get a full picture of experiences, the industrial application is followed up with semi-structured interviews. A detailed description of the case study methodology adopted is found in Section 3. Findings of the overall application are presented and discussed in relation to the notions of the study and results of other field studies (Section 5).

2 Proposition – A method for balancing while synthesising

This section describes the proposed design method for balancing properties while synthesising a product concept. The philosophy underlying the method and expected outcomes are also presented.

2.1 Overall description of the proposed design method

A starting point underlying the proposed method is that an efficient balancing support presupposes that concept synthesis and balancing are done in parallel. The fact is that most property synergies or conflicts become evident – and can be best managed – when different solution proposals are combined. Another phenomenon is that concept solutions presented in a team tend to quickly become fixed in people's minds, making balancing after the actual concept synthesis more difficult. Specifically, the driving thought behind the method is to analyse and utilise the interplay between different sub-systems of the product, in order to reduce the risk for sub-systems and components being optimised in their isolated context.

Figure 1 outlines the main activities of the proposed systematic method. The work process thus starts with setting up a desired performance profile, based on the most central requirements for the envisaged product or system. The next activity is to generate or collect solution proposals per function (or per sub-system, if found more adequate in the specific context) and arrange them in a morphological matrix. The morphological matrix is then re-arranged with regards to the relative complexity of the functions (or sub-systems). The most complex function (sub-system) is put at the top of the matrix, etc. An overall concept proposal is then elaborated by stepwise synthesis, working top-down in the matrix. Each synthesis step involves active seeking for synergies, analysis and description of synergies, and description of added ideas and integration opportunities. Performance and performance/cost ratio shall always be evaluated for the overall concept integration, but may also be done for sub-integrations, for instance after each synthesis step. If overall performance is not adequate, or if for any other reason more concept alternatives are desired, the complete synthesis procedure is repeated. Individual performances poorly fulfilled can be tackled by concept evolution. The outcome of the procedure is thus one promising product concept or several, for which synergies have been utilised, and performance/cost ratio been assessed.

The method implies that the work effort is focused on solution combinations and integrations assessed promising. Thus, time is not spent on analysing interactions in every theoretically possible solution combination. Generally, the thought is that a procedure involving synergy and multi-property considerations shall result in a high quality synthesis.

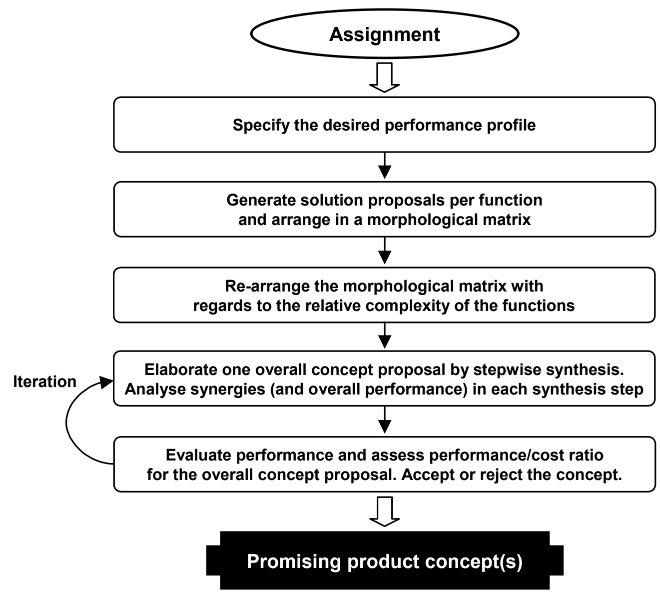


Figure 1. Outline of the proposed synthesis and balancing method.

2.2 Desired performance profile

The performance profile (figure 2) is intended to provide a cognitive map of the most important performance requirements for the envisaged product. The graph layout is selected taking influence from “value profiles” proposed by Pahl and Beitz [11]. Here, the length of the bars corresponds to the targeted performance level, and their thickness to the property’s relative weight in its system context. For each property, a minimum acceptable performance is set in order to avoid unsatisfactory performance of individual properties. Thus, in evaluating a concept proposal, over-fulfilment of some requirements can just partly compensate for poor fulfilment of others. The grade scale (0 – 10), see table 1, is user-value-oriented, and developed by combining and enhancing value scales according to VDI 2225 [11], and the Swedish car manufacturer’s standard. Since the scale concerns performance in the sense of user value, the relationship between performance grade and technical factors is not necessarily linear. Using the scale, the performance can be judged referring basically to its operational context – adopting perspectives such as “Adequate” and “Ideal”, or reflecting current market references – adopting perspectives such as “Average” and “Unique”.

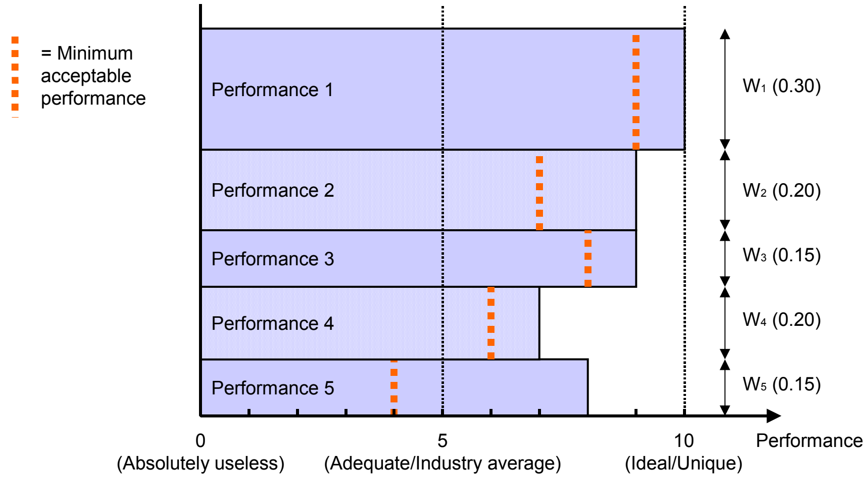


Figure 2. Desired performance profile.

Table 1. Meaning of the performance grades of the value scale.

Grade	Meaning	Customer reaction
0	Absolutely useless	Customer wants repurchase
1	Unacceptable	Customer wants repurchase
2	Unsatisfactory	Most customers complain
3	Just tolerable	Average customer complains
4	Slightly worse than average	Some customers complain
5	Adequate/Average	Most customers satisfied
6	Slightly better than average	Most customers satisfied
7	Good	Satisfied customers
8	Very good/Among the best	Happy customers
9	Outstanding	Impressed customers
10	Ideal/Unique	Excited customers and journalists

2.3 Morphological matrix – Alternative solution proposals per function

The morphological matrix [12] constitutes a pallet of alternative solution proposals, organised per function or sub-system. When applied in the cross-functional development context concerned in this study, the solution proposals should be generated by all project parties in co-operation, or at least originate from all parties. Thus, all available ideas can be captured, and a shared holistic view on the idea flora is supported. In order to maximise the potential for a concept synthesis utilising synergies, the morphological matrix is re-arranged with regards to the relative complexity of the functions (or sub-systems), see upper part of figure 3. Complexity is assessed in terms of the number (and effect) of potential interactions with other functions (sub-systems). The most complex function (sub-system) is put at the top of the matrix, etc.

2.4 Synthesis and balancing procedure involving synergy analysis

An overall concept proposal is elaborated by stepwise synthesis, working top-down in the morphological matrix. Each synthesis step involves active seeking for synergies between solution proposals on consecutive function (or sub-system) rows. Solution combinations (integrations) perceived promising are subject to a synergy analysis, which will provide deeper insight about the combination, and, in turn, claim for or against the combination. Synergies are analysed and described regarding performance, geometry (e.g., packaging efficiency, interfaces, tolerances), materials, and manufacturing. Potential performance of a solution combination otherwise assessed should also be noted, especially in cases when actual synergy thinking is not applicable. On the whole, the synergy analysis aims to support synthesis decisions facilitating overall performance and performance/cost ratio, by integrating solutions that harmonise, or even discovering function-sharing opportunities.

Figure 3 illustrates the procedure focusing on the first two synthesis steps. As seen in the figure, synthesis step 1 involves function rows 1 and 2, and its associated synergy analysis, and synthesis step 2 adds function row 3 for consideration. Note that (after function rows 1 and 2) synergies are analysed between the cumulative sub-integration already created and solutions on the next function row subject to integration. Thus, the overall concept is synthesised by stepwise integrating solutions, function by function (sub-system by sub-system), and synthesis step (n-1) completes the concept.

The synergy grades that are set in the synergy analysis (see figure 3) are intended to indicate how well the considered solutions interact with reference to each criterion, or, secondarily, to indicate potential performance otherwise assessed. The description concretises what the actual interaction effect is, and thus also the rationale behind the grade. Table 2 summarises definitions of the synergy grades. A "high synergy" means that the solutions in interaction clearly produce a spin-off value with reference to the criterion assessed. Thus, the performance of the solution combination is clearly higher than the sum of the individual items' performance. Consider this example of a car: "combining a steel floor panel and a thick floor carpet creates a sound-insulating (and shock-absorbing) double wall". Alternatively, the combination uses less resources than the individual items one by one, for instance by "using the same material for several functions". The next grade, "medium synergy", means that the solutions generally fit well together with reference to the assessed criterion, or that there is a clear potential for a synergy, though sensitive to other decisive factors. Finally, "no synergy" means that the combination as such adds no value, and "conflict" that it is even hazardous. Having the completed synergy analysis of a synthesis step, a solution combination should be considered effective if "high" and "medium" synergies are generally identified. As a guideline, there should not be any "no" or "conflict" grades. If the result is not acceptable, one or more synthesis steps are repeated.

Table 2. Synergy grades and their definitions.

Synergy grade	Definition	Example
● (high)	The performance of the solution combination is clearly higher than the sum of the individual items' performance.	"combining a steel floor panel and a thick floor carpet creates a sound-insulating (and shock-absorbing) double wall" (a car is considered)
◑ (medium)	The solutions generally fit well together with reference to the assessed criterion.	"adding a trim insert to the door panel provides for variant flexibility" (a car is considered)
○ (no)	The solution combination as such adds no value with reference to the assessed criterion.	"painting stainless steel makes no difference with respect to corrosion"
⊗ (conflict)	The solution combination is hazardous with reference to the assessed criterion.	"aluminium rivets in a steel boat hull means an evident risk with respect to corrosion"

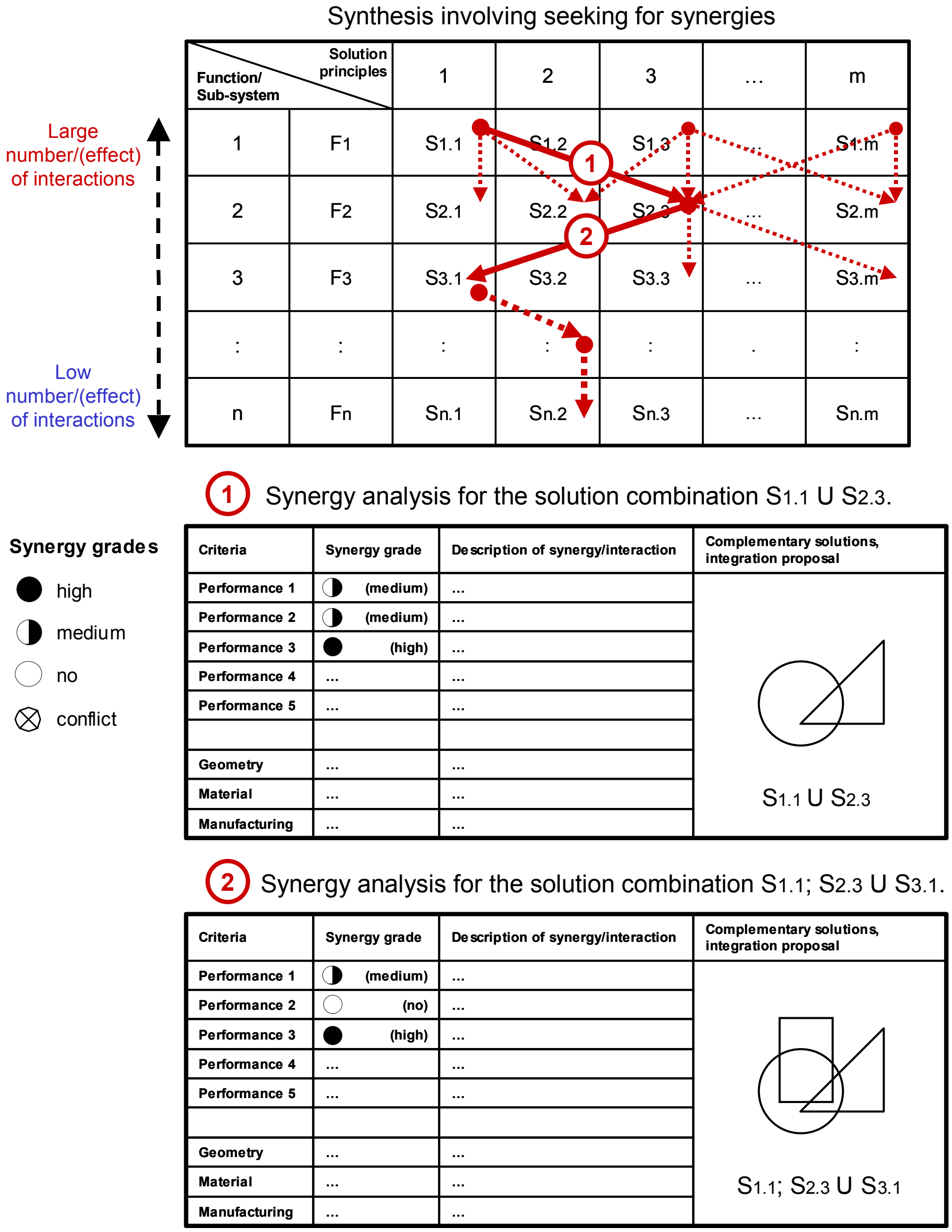


Figure 3. Synthesis steps 1 and 2 including their respective synergy analysis exemplified.

The next sub-section will present the approach for evaluating performance and assessing performance/cost ratio of a concept proposal. It should be pointed out that performance and performance/cost evaluations may also be done after each synthesis step – if found efficient (e.g. considering time consumed versus importance of overall performance and cost aspects).

2.5 Performance evaluation and performance/cost assessment

Performance of a concept proposal (or a sub-integration) is evaluated with reference to the performance profile presented in figure 2, and using the value scale presented in table 1. If used for concepts under synthesis (sub-integrations) the performance has to be seen as potential. The assessed performance grades of a concept are highlighted in the graph for clarity, see figure 4. An overall weighted performance (value) is then represented by the sum of the products of each performance grade and weight factor [11]. The performance/cost ratio is then calculated by dividing the overall weighted performance with the cost estimated to realise the concept (or sub-integration), confer [2], [11]. The diagram, right in figure 4, provides a graphical representation of the performance/cost ratio. Adopting the philosophy in this study, the solution space is constrained by the minimum overall weighted performance, the performance/cost ratio of an average solution (=1), and possibly also a cost limit.

Repeat the complete synthesis procedure if overall performance or performance/cost ratio is not adequate, or if for any other reason more concept alternatives are desired. Individual performances poorly fulfilled may be tackled by concept evolution. Of course, also over-fulfilment of requirements can be tackled by concept evolution, especially if they are found to be related to high costs or conflicts with other requirements.

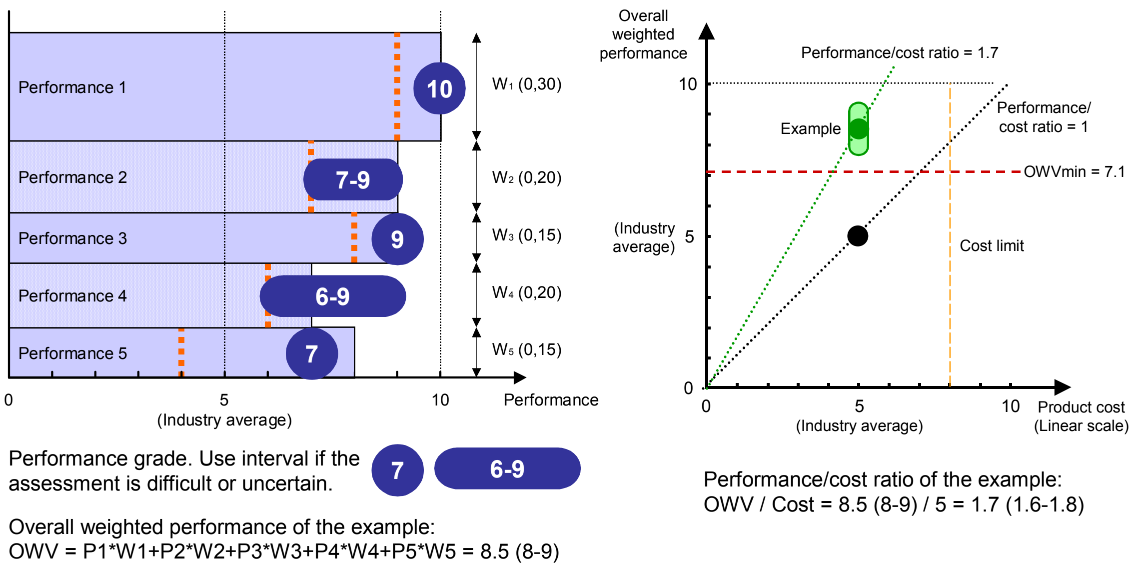


Figure 4. Performance evaluation and performance/cost assessment exemplified.

3 Case study methodology adopted in the industrial application

In doing and evaluating the industrial case study, a *systems approach* is generally adopted, meaning that the problem situation is seen from a holistic perspective, and a large number of dynamic factors are assumed to affect the product development system [13]. In line with this thinking, data is collected and analysed adopting a qualitative approach. The method application is carried out practising *action research*, meaning that practical problem solving, scientific research, and competence development is combined through a multidisciplinary collaboration [14]. In this research context, action research provides a unique possibility to evaluate and enhance design methods in running operations, as well as to get access to a real-life development environment. At the same time, it should be emphasised that action research involves a certain amount of judgement, and that the researcher presence affects the industrial as well as the scientific result. The latter is closely related to the fact that affecting parameters are not constant, for instance due to the learning effect on team members. Moreover, the effects of the applied methods are difficult to measure and verify in a mathematical sense. Therefore, this kind of research approach requires rigorous data collection and a detailed documentation of the case, in order to minimise bias and maximise transparency of the study and its results. In line with this, the principle of multiple information sources is adopted, and original documentation of the application is presented.

Data sources related to the application include project documentation, semi-structured interviews, and participative observation with associated logbook notes. The data sources complement one another, even if the interviews are considered as the most important source regarding the experiences of the application. All team members have been interviewed. The interview guide used includes both open and more specific questions. Each conversation theme starts with open questions in order to give the interviewee the opportunity to spontaneously describe experiences and opinions in his or her own words. Then follows more specific questions, pinpointing notions of the method proposition, in order to bring forth additional information completing the description of the theme. In order to minimise bias due to concern about the action researcher, the respondent was always interviewed by two researchers, of which both took notes simultaneously with the respondent's answers. After each interview session, the notes were collated, transcribed, and checked by the researchers involved in the interview in question. The full transcription was then sent to the interviewee for approval and possible changes. The analysis of the information emerging from the different information sources has been done in an integrated fashion, and the material has been condensed using stepwise data reduction. Finally, findings are put in relation to the initial notions of the study, and results of other field studies.

4 Industrial application of the proposed design method

4.1 Setting for the application

The method was applied on-site at the car manufacturer, within an ongoing advanced engineering project dealing with the conceptual design of a door module. A door module can be described as a multi-technology product integration involving parts of several car systems. In the advanced engineering project the primary boundary includes interior trim, door mechanics, and audio. A seven-member cross-functional team (plus the researcher) took part in the concept development work, using the proposed synthesis and balancing method. The team included development engineers representing exterior (two engineers of which one was the project leader), interior, and audio; one manufacturing engineer; one safety specialist; and one solidity specialist. All of them are highly skilled in their respective profession, but have limited experience of systematic design methods. The researcher's (i.e. the author's) role was to facilitate the use of the design method. The project leader also took part in the development of the method and planning the application. All engineering information was generated by the team members from the car manufacturer or was given in the prerequisites for the advanced engineering project. The project leader and the researcher were responsible for documenting the results. The actual method application was carried out during the period November 2004 to January 2005, mainly through five half-day sessions. Essentially, the application corresponded to one run of the overall synthesis and balancing method.

4.2 The work of the team using the proposed design method

Essentially, the project leader elaborated the *desired performance profile* (figure 5) on the basis of prerequisites and targets for the next generation door module. The performance of the current door module was also assessed and indicated in the graph. The delta between current and targeted performance thus indicates project drivers. The profile was then adjusted and agreed in the team as a whole.

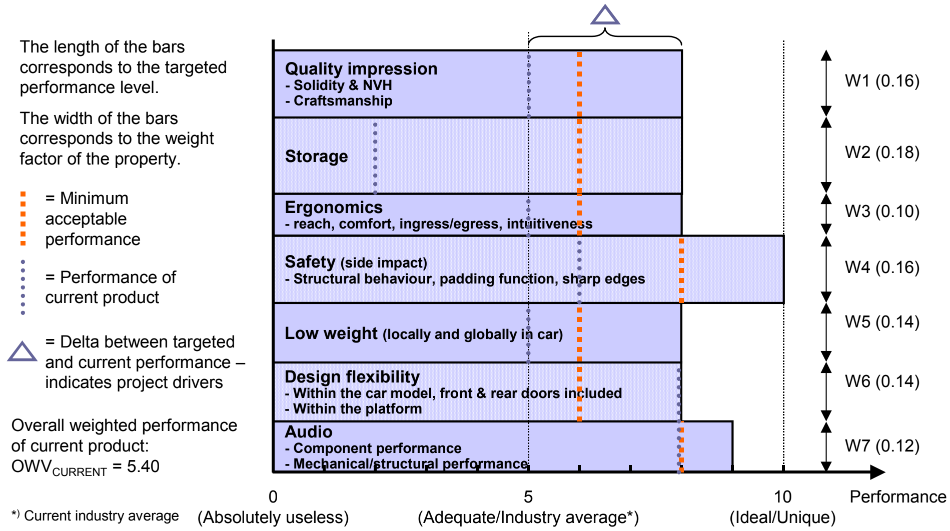
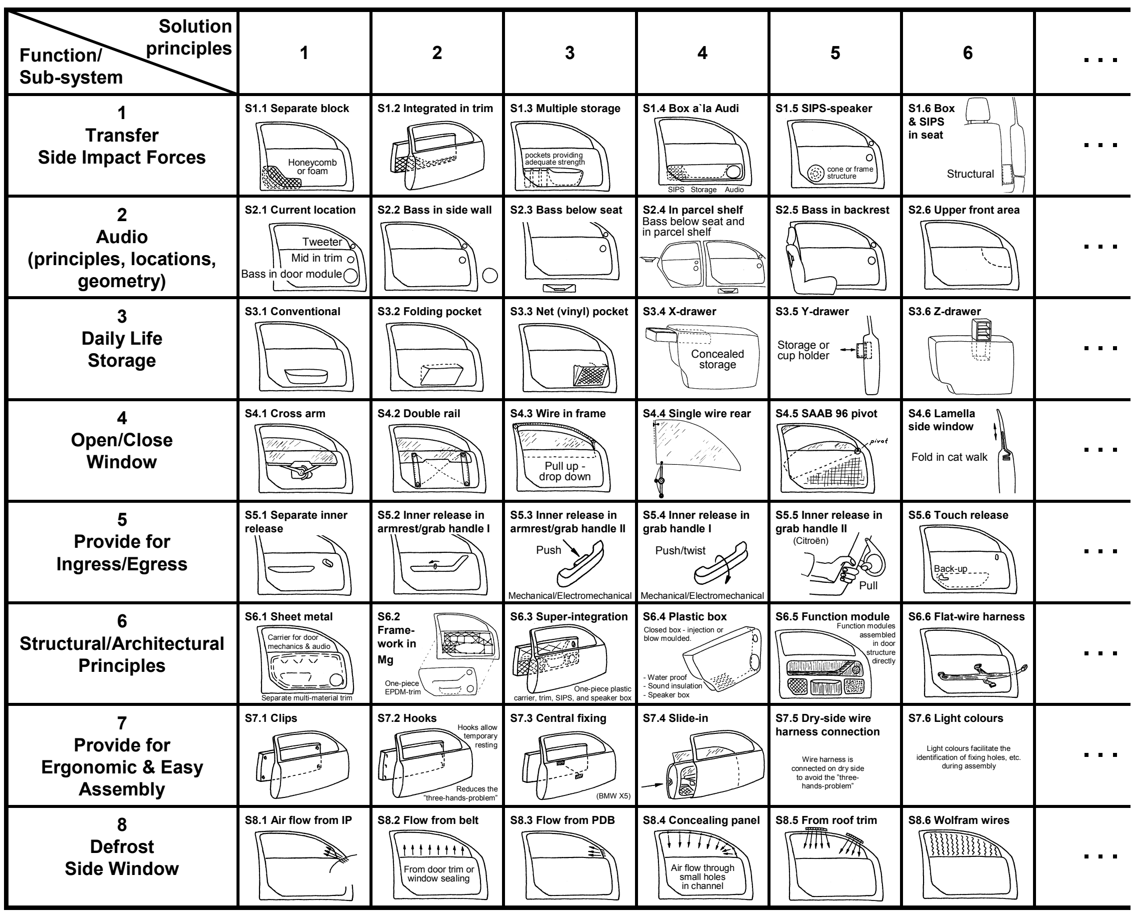


Figure 5. Desired performance profile for the next generation door module.



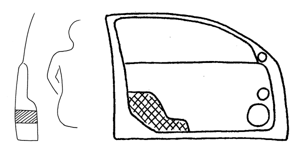
Function/ Sub-system \ Solution principles	1	2	3	4	5	6	. . .
1 Transfer Side Impact Forces	S1.1 Separate block (Honeycomb or foam)	S1.2 Integrated in trim	S1.3 Multiple storage (pockets providing adequate strength)	S1.4 Box a`la Audi (SIPS Storage Audio)	S1.5 SIPS-speaker (cone or frame structure)	S1.6 Box & SIPS in seat (Structural)	. . .
2 Audio (principles, locations, geometry)	S2.1 Current location (Tweeter; Mid in trim; Bass in door module)	S2.2 Bass in side wall	S2.3 Bass below seat	S2.4 In parcel shelf (Bass below seat and in parcel shelf)	S2.5 Bass in backrest	S2.6 Upper front area	. . .
3 Daily Life Storage	S3.1 Conventional	S3.2 Folding pocket	S3.3 Net (vinyl) pocket	S3.4 X-drawer (Concealed storage)	S3.5 Y-drawer (Storage or cup holder)	S3.6 Z-drawer	. . .
4 Open/Close Window	S4.1 Cross arm	S4.2 Double rail	S4.3 Wire in frame (Pull up - drop down)	S4.4 Single wire rear	S4.5 SAAB 96 pivot (pivot)	S4.6 Lamella side window (Fold in cat walk)	. . .
5 Provide for Ingress/Egress	S5.1 Separate inner release	S5.2 Inner release in armrest/grab handle I	S5.3 Inner release in armrest/grab handle II (Push; Mechanical/Electromechanical)	S5.4 Inner release in grab handle I (Push/twist; Mechanical/Electromechanical)	S5.5 Inner release in grab handle II (Citroën) (Pull)	S5.6 Touch release (Back-up)	. . .
6 Structural/Architectural Principles	S6.1 Sheet metal (Carrier for door mechanics & audio; Separate multi-material trim)	S6.2 Frame-work in Mg (One-piece EPDM-trim)	S6.3 Super-integration (One-piece plastic carrier, trim, SIPS, and speaker box)	S6.4 Plastic box (Closed box - injection or blow moulded. - Water proof - Sound insulation - Speaker box)	S6.5 Function module (Function modules assembled in door structure directly)	S6.6 Flat-wire harness	. . .
7 Provide for Ergonomic & Easy Assembly	S7.1 Clips	S7.2 Hooks (Hooks allow temporary resting; Reduces the "three-hands-problem")	S7.3 Central fixing (BMW X5)	S7.4 Slide-in	S7.5 Dry-side wire harness connection (Wire harness is connected on dry side to avoid the "three-hands-problem")	S7.6 Light colours (Light colours facilitate the identification of fixing holes, etc. during assembly)	. . .
8 Defrost Side Window	S8.1 Air flow from IP	S8.2 Flow from belt (From door trim or window sealing)	S8.3 Flow from PDB	S8.4 Concealing panel (Air flow through small holes in channel)	S8.5 From roof trim	S8.6 Wolfram wires	. . .

Figure 6. Morphological matrix capturing solution proposals generated in the team.

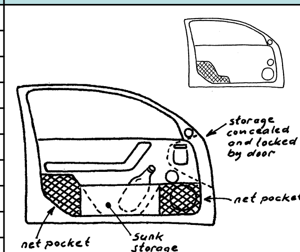
The *alternative solution proposals per function* were generated through a brainstorming session involving all team members. In principle, the brainstorming focussed on one function at a time. The functions were predefined by the project leader and the researcher in collaboration, and refer to the main functions of the door module. Figure 6 shows a part of the resulting (and rearranged) morphological matrix, including eight functions and up to 22 solution proposals per function.

In doing the *concept synthesis including synergy analysis*, the team was split into two groups. In total four complete concept proposals were generated through two half-day sessions. The method was applied making performance/cost assessments for complete concepts only (see next sub-section). Figure 7 shows three of the seven synthesis steps for "Concept A", and their associated synergy analysis. Notice that, in practice, multiple (partial) solutions were selected for some functions. The synergy analyses then still focus on interactions across functions. Maybe, the teams could have considered to increase the function resolution of the morphological matrix, or to distinguish partial and system solutions.

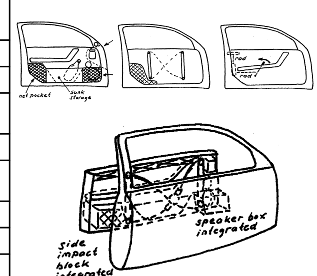
Concept A, Synthesis step 1

Criteria	Synergy grade	Description of synergy/interaction	Complementary solutions, integration proposal
Quality Impression	◑	OK	
Storage	◑	Possibly imposes limitations to storage volume between pelvis pusher and speaker	
Ergonomics	◑		
Safety	◑		
Low weight	◑		
Design flexibility	◑		
Audio	◑		
Geometry	●	Solutions fit well together in respect of geometry	The integration means a further optimised geometry in respect of side impact safety
Material	◑		
Manufacturing	◑		S1.1; S1.8 U S2.1

Concept A, Synthesis step 2

Criteria	Synergy grade	Description of synergy/interaction	Complementary solutions, integration proposal
Quality Impression	◑	Risk for some noise when items stored in front of bass speaker	
Storage	●	Utilises volume in front of bass speaker and pelvis pusher	
Ergonomics	●	Good flexibility for placing items	
Safety	◑	No compromises	
Low weight	◑	Net pockets are weight efficient	
Design flexibility	◑	Some impact on design flexibility, positively or negatively	
Audio	◑	No compromises (possibly rattle from items stored at bass speaker)	
Geometry	Not assessed		
Material	Not assessed		
Manufacturing	Not assessed		S1.1; S1.8; 2.1 U S3.3; S3.5; S3.18; (S3.21)

Concept A, Synthesis step 5

Criteria	Synergy grade	Description of synergy/interaction	Complementary solutions, integration proposal
Quality Impression	●	Enables pre-testing of complete assembly. Flat wiring reduces the risk for rattles	
Storage	●	Plastic carrier enables deeper storage and a more complex shape	
Ergonomics	◑		
Safety	◑	Pelvis pusher integrated in carrier. Local shear sections separate pelvis pusher from carrier in side impact.	
Low weight	●	Function sharing – One component integrates several functions	
Design flexibility	◑	Advantages due to material. Disadvantages due to a large single component.	
Audio	◑	Loudspeaker box integrated in carrier	
Geometry	◑	Island units – no accumulated tolerances. Flush and gap for components assembled finally may be critical	
Material	●	Same material used for several functions	S1.2; S1.8; 2.1; S3.3; S3.5, S3.18; (S3.21); S4.2; S5.2; S5.9 U S6.3; S6.6
Manufacturing	●	Fever components due to integration	

● high synergy ◑ medium synergy ○ no synergy ⊗ conflict Sx; Sy; Sz set of solutions U inter-function focus

Figure 7. Synthesis steps 1, 2, and 5, and their associated synergy analysis for "Concept A".

The *performance evaluation and performance/cost assessment* of the four synthesised concepts were conducted through two half-day sessions having the full team present. Basically, the concepts were evaluated with reference to the set up product profile. Since the four concepts were evaluated at the same time, they were in practice also compared relatively to one another. Figure 8 exemplifies the performance evaluation showing the results for "Concept A". Note that no performance is below acceptance limit. For the other three evaluated concepts, one or two performances are slightly below acceptance limit. The overall weighted value is similar for the four evaluated concepts. Figure 9 then shows the performance/cost assessment of all four concepts. As seen in the figure, all developed concepts have an overall performance/cost ratio better than the current concept, but the costs assessed are actually higher. The cost assessment is based on a cost-split of the current door module. All in all, 13 cost issues related to detail cost and assembly were considered.

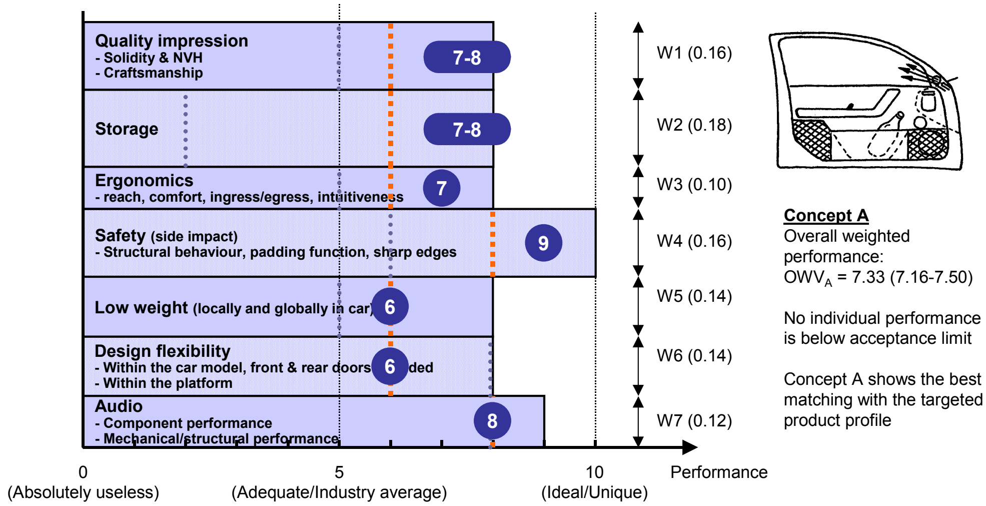


Figure 8. Example of the performance evaluation ("Concept A").

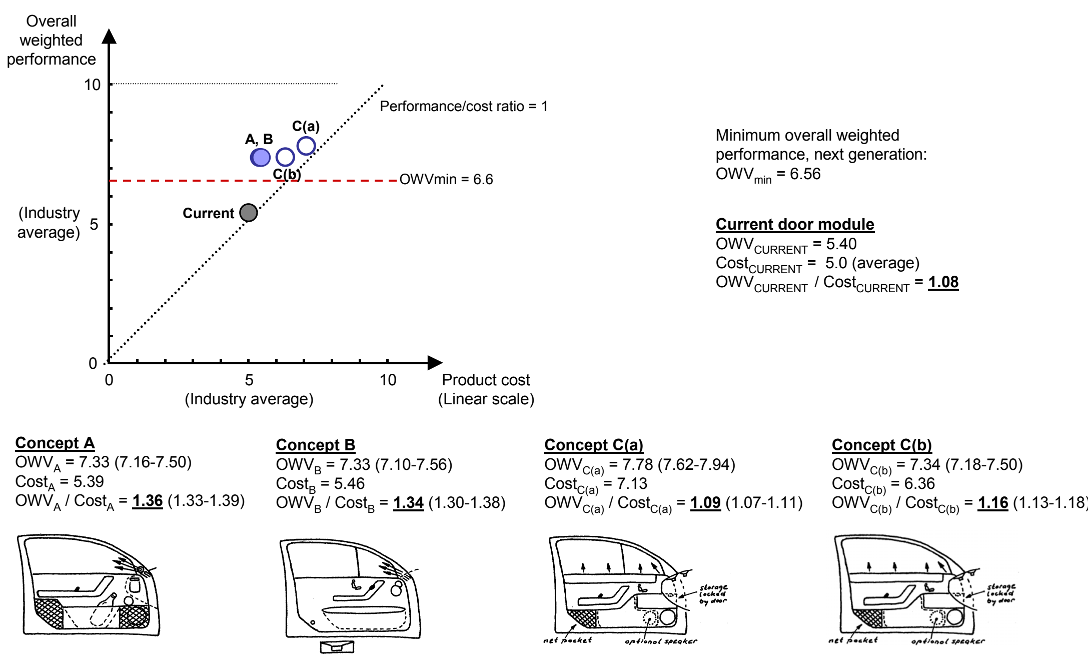


Figure 9. Performance/cost ratio for the four synthesised concepts (indexed cost).

5 Findings and discussion

This section condenses the observations and experiences from the industrial application. The findings are also put in relation to notions of the method proposition, earlier empirical research [1], [8], [15], [16], [17], and important prerequisites for successful implementation of tools and methods [9].

5.1 General observations from the application

The teamwork was generally characterised by great interest and enthusiasm. Consequently, the team members were always eager to plan and tackle the next activity of the method. They generally chose to prioritise the concept sessions, in competition with other activities on an essentially full agenda. Thus, the average presence at the sessions was high (>85%).

Examining the result and the documentation of the teamwork, one can conclude that the concept proposals produced all have an improved overall performance as well as performance/cost ratio. They also generally incorporate synergies, in the sense that the sub-solutions match one another well with reference to the product properties focused. However, in applying the method it was shown that a synthesis decision cannot solely be guided by synergies, but has also to be based on properties of a solution combination assessed in a more general sense. For instance, two concepts under synthesis were rejected due to foreseen optimisation problems in upcoming product development work.

During the concept synthesis – when the team was split in two groups – one of the groups applied the synthesis procedure in a very disciplined manner, while the other group made synthesis of multiple functions instead of the intended stepwise procedure. Accordingly, the groups made their concept syntheses in seven or two steps respectively. Both groups, however, used the synergy analysis to analyse interplays in the solution integrations. Inspecting the documentation, one can notice that the group making the synthesis in two steps made more mistakes in terms of missing functions, and contradictory combinations. Concretely, this group left out two subsystems for integration, and the resulting concepts were also less balanced with reference to the desired product profile. Nevertheless, the overall weighted performance was similar for all concepts generated.

5.2 Effects of the method with focus on the product concept

Referring to the team members' responses on open-ended questions, the applied method generally supports a holistic view of the product and its properties, while the usual approach at the car manufacturer is seen as more detail-oriented. Reflecting on the responses, the method is also a means to "achieve a better problem understanding and problem solving" [17]. As generally stated by the team members, prerequisites are brought from all areas in an early phase. Thus, all involved are provided an understanding of each other's system areas and product properties, as well as the relative importance of different systems and properties. It is stated, furthermore, that several aspects and systems, and their interactions, are already considered in the concept development, e.g., for the benefit of early incorporation of user needs, and fewer change loops. Some of the participants also emphasise the method's role in supporting broad-minded creativity, though guided by defined criteria.

The improvement in overall performance was clearly confirmed by the team members, and they generally think that all important properties set-up have been incorporated. Some of the team members also state, however, that issues not included in the prerequisites, such as technology at detail level, may affect the final result. Specifically, it is said that user functions have been considered to a greater extent than would usually have been the case. Regarding the issue of design methodology, some of the respondents emphasise that the follow-up is important, and mean that it is not enough to consider the prerequisites in the beginning, confer [1], [17]. As responses showed, a strong point of the applied method is the continual presence of the prerequisites. It is also said that, following the usual work practice, one would not have thought this creative in providing the targeted performance.

The team members also find the property balance significantly improved, which is credited to the parallel consideration of different property areas, and the presence of the performance profile set up. A more socio-cultural view presented is that balancing is automatically attained when all competencies are involved in the design process. A related view concerns the incorporation of alternative solutions in the balancing process: Usually the balancing activity concerns the property levels as such, and is a matter for requirements specialists. Then it is more difficult to identify the synergies in favour of optimising the overall concept.

Regarding the concepts' resulting performance/cost ratio, the team members' views differ. The performance/cost ratio as such is improved, which is attributed to the enhanced overview and follow-up of the system and its prerequisites. However, the concept proposals produced in the team are actually assessed more expensive and cost is usually given a high priority in car projects. Two of the respondents even consider increased cost being a risk with the method: "Definition of different target parameters makes one prioritise these, while striving to sharpen them all". Reflecting on the views given, performance/cost assessments should be considered in each synthesis step, as presented as an alternative in Section 2.4. On the other hand, one of the respondents is sure that early cost focus locks many doors, and the important thing is to study how solutions match one another in favour of an effective concept principle.

5.3 Engineering management issues

Supported by interview responses, use of the method facilitates project management. Having a common method to follow, it is easier to synchronise the team members' efforts, while utilising experience and expertise of each team member [8], [16]. As formulated by one of the interviewees: "I see a chance with the method to keep in step with the others". Many of the individual team members are also very satisfied with the fact that the functions they are responsible for have been incorporated into the concepts. Specifically, a lot of ideas within someone's actual responsibility were brought to light from the other team members.

More related to strategic issues, the method is generally seen as a potential support in creating overall product offers that are agreed across several disciplines. Furthermore, the method is considered to provide every organisational function the possibility to test their strategies, also towards other function areas. For instance, it can be shown if one's strategy facilitates the complete product or just ones' own area of responsibility. Specifically, as raised by one of the team members, use of the method might result in commonality strategies being confronted. Thus, the method's focus on multi-objective synergy thinking stands in contrast to the often-adopted platform commonality strategies at component level.

The team members all think that the method supports making agreed decisions, as well as the establishment of common views and mutual understanding [9]. This is attributed to the availability of all relevant information, confer [9], and the fact that the solutions are produced in collaboration. In addition, the way of setting grades is said to concretise the concepts' output and thus eases the decision-making. The communication as such was also found to work very well, which is a typical good result of method applications as earlier reported [15].

The application of systematic design methods might result in over-formalisation and unnecessarily complex work procedures [15]. Here, the team members think that the method's level of structure is adequate, and that the included steps and their flow feel natural.

Specifically, as pointed out: “a structure is good to focus one’s creative efforts on the right issues”. Some team members, however, found the synergy analysis difficult. Time consumption is also often discussed in the context of systematic design methods [15]. Here, the team members generally find the result far-reaching with reference to the time consumed. This is particularly interesting, since they had limited experience of similar methods. Without exception, the team members are positive about using the method in future, preferably having a politically unbiased “method champion” [9] present.

6 Conclusion

The paper presents a systematic, semi-quantitative design method allowing engineering assessment and use of vague information available in the early concept stages. The method constitutes decision support in cross-functional work, and focuses attention on synergies between sub-solutions in order to facilitate overall performance and performance/cost ratio. Use of the method implies focus on the effectiveness of the overall product integration, minimising the risk of wasting time on optimising detail solutions in their isolated context. The method does not guarantee the ultimate, optimal concept, since all possible combinations are not studied, and factors not included in the method may affect the overall performance, but it produces an effective concept solution using minimal resources.

The industrial application was successful in terms of both product result and team spirit. In comparison to the current product, the concept proposals synthesised in the team generally have a better property balance as well as an improved performance/cost ratio, but are also assessed more expensive. Generally the team members are of the opinion that the method encourages creative thinking, provides essential support for consideration of overall product solutions and property balance, and supports cross-functional co-operation.

The complete set of findings presented here is basically bound to the context of the method application. Nevertheless, in a holistic sense many of the individual findings are consistent with those of other empirical case studies. However, in a single case study transferability is just as important as generalisation. The detailed documentation of this study enables the transfer of experiences to secondary observers and researchers that may want to apply the findings in other settings. The proposed concept synthesis and balancing method as such was well accepted by the team members (confer “verification by acceptance”, [10]).

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