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USING THE DSM TO SUPPORT THE SELECTION OF PRODUCT CONCEPTS

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Keywords: concept selection, morphological matrix, handle complexity, compatibility, DSM

1 INTRODUCTION

During the conceptual design phase the basic working principle or concept of a product is defined [1]. The selection of a specific concept is a very important step in the development process because this decision has multiple effects on the following phases and the final product.
In this early stage the field of solutions should be as wide as possible. To achieve this and to handle complexity at the same time it is common to use the method of factorization [1]. A complex system is divided into separate manageable sub-problems which can be solved individually. The consistent combination of partial solutions leads to the overall solution (concept). Thereby a high number of theoretical concepts can be created out of a small number of sub-problems and solutions. This high number has to be reduced so that the selection of an optimal concept is possible.
The presented approach provides a systematic assistance in the selection of an overall concept by consequently eliminating inconsistent solutions and identifying promising combinations.

2 BASIS AND RELATED RESEARCH

A well introduced method to order and systemize the allocated partial solutions is the usage of a one dimensional ordering scheme. In this morphological matrix developed by Zwicky [2] the sub-functions are allocated in the fist column and the associated partial solutions are arranged in the belonging row. The combination of one partial solution out of every row leads to the overall principle solution or product concept. The number of theoretical possible concepts which can be generated is the multiplication of each number of partial solutions in each row (e.g. 4 sub-problems with each 3 partial solutions result in 88 alternative concepts). In most cases no resources are available for checking up and evaluating all these theoretical overall concepts. Therefore methods are needed which allow to reduce this high number of alternatives significantly.
To fulfil this task a compatibility matrix [3] in which incompatibilities among two different partial solutions are marked can be used. Through this inconsistent concepts with non compatible partial solutions can be identified and eliminated from further considerations. A different method which also visualizes the possible concepts is the usage of tree structures [3]. In these trees of alternatives all possible combinations of solutions are carried out systematically. In case of an incompatibility among two solutions the according branch is aborted. The remaining complete branches represent the possible and consistent overall concepts.
In general both approaches represent interdependencies among different partial solutions. Networks like this consisting of only one type of domain, in this case partial-solutions, can be described by a design structure matrix (DSM) [4]. A comparable approach has been presented in the field of variant management for analyzing product ranges [5]. The focus there lies on the identification of clusters of different variants and it gives impulses for setting up suitable design modules.

3 IDENTIFICATION OF CONSISTENT CONCEPTS BY USING THE DSM

Transferred to the systematic combination and selection of concepts in early phases a matrix is needed which represents all possible connections between the partial solutions. Therefore the "classic" compatibility matrix is transformed into a compatibility design structure matrix or "consistency matrix" in which all compatible combinations of elements are marked (see figure 1). This matrix can easily be created by inverting every element of a given compatibility matrix. Compared to the classic one the new compatibility DSM can be seen as an inverted or negative image.
Regarding the practical application the designer can still mark incompatible combinations because this number is much lower in most cases. Afterwards the inverted matrix can be calculated automatically.

Since the connections of the elements are undirected, the compatibility DSM is completely symmetrical and it is only necessary to fill in one half (like in the original one). Furthermore only combinations from different lines of the morphological scheme have to be considered because it is only allowed to select one partial solution for each sub-function [2].
With this representation it is possible to identify consistent overall concepts by performing a cluster analysis. A consistent and complete concept correlates with a completely interlinked cluster. Thereby the size of the cluster has to meet the number of partial functions (rows in the morphological scheme). This is due to the fact that all elements contained in a solution have to be compatible to each other and that every partial problem has to be fulfilled. To validate this assumption the identified clusters were compared to a manually created tree of alternatives. The results confirmed that structure and number of the completely interlinked clusters are identical to the complete branches.
Smaller completely interlinked clusters can be seen as a partial solution for the overall problem. This is especially interesting if the sub-functions are arranged in a specific order that represents their importance. Elements which are not contained in any completely interlinked cluster are eliminated from further considerations. In that way the number of theoretical solutions can be reduced significantly. The identification of clusters can be done by a computational algorithm so that the user is completely exempted from all combination activities.
The structure and interdependencies of the partial solutions can also be represented by strength based graphs [4]. In these graphs partial solutions which are contained in many different overall solutions are arranged in the middle. Solutions with fewer connections or those which are not contained in any completely interlinked cluster can be found on the border of the structure (cf. [5]).

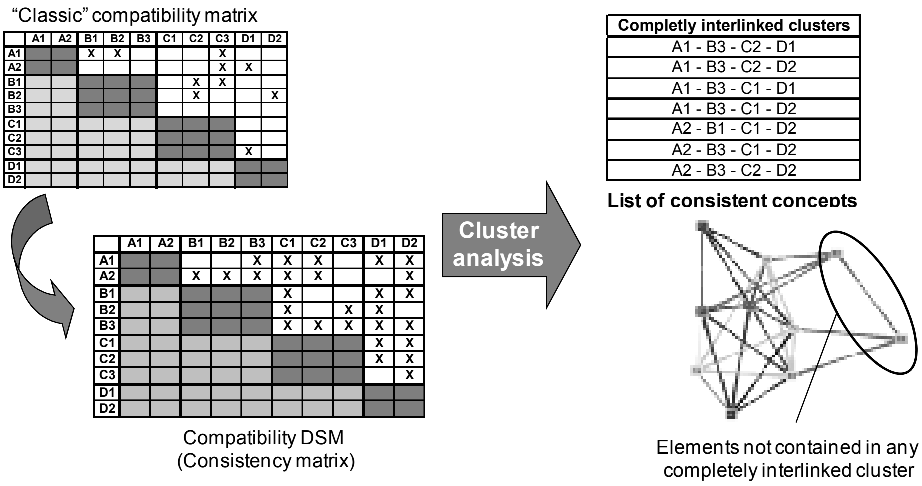

Figure 1. Matrix of compatibility to identify completely interlinked clusters

4 EXTENDING THE MATRIX TO GAIN A RANKING ORDER

The simple identification of consistent solutions and elimination of unfitting partial solutions is only the first step during the process of concept selection. In general the remaining number is still too large to be analyzed and evaluated during embodiment design. Considering the importance of this step the identification of an overall concept which meets the requirements best is needed [1].
Therefore the presented compatibility-DSM is extended by weighting factors (see fig. 2). These factors represent a positive or negative influence between two solutions. Instead of just checking the (in)compatibility, the degree of positive or negative influence between two concepts is inserted in the matrix. Two partial solutions which have mutual positive influence or work perfectly together receive a high value, poor combinations receive low factors. The evaluation of all pair wise combinations of partial solutions has to be carried out by the designer. Therefore different evaluation methods can be used (cf. [6], [7]). In this context adequate evaluation criteria and a fitting value function (e.g. linear or logarithmical) have to be defined. It is also important that the level of information of all partial solutions is almost identical. Otherwise the results are not reliable and promising concepts may be eliminated accidentally [1], [7].
To support the selection of a concept a ranking order can be calculated from the given weighting factors. The quality of a concept is represented by the sum of all the weights in a completely interlinked cluster. Concepts with a high value contain positive evaluated combinations of partial

solutions; concepts with a lower sum include poor or average combinations. Based on this a ranking of consistent overall concepts can be derived easily. This way of calculating a ranking out of the weights is possible because all considered clusters consist of the same number of elements and connections. Not completely interlinked or smaller clusters were eliminated in the first step. The generation of the ranking based on the extended compatibility matrix can be done completely automatically. The designer can concentrate on generating and evaluating the partial solutions.

	A1	A2	B1	B2	B3	C1	C2	C3	D1	D2
A1					0.3	0.1	0.3		1.0	0.3
A2			0.1	0.5	0.1	0.5	0.1			1.0
B1						0.1			1.0	1.0
B2						0.5		1.0	1.0	
B3						0.1	0.3	1.0	0.3	1.0
C1									0.3	1.0
C2									1.0	0.3
C3										1.0
D1										
D2										

Extended compatibility matrix

Ranking	Cluster	Sum of weights
1	A1 - B3 - C2 - D1	3,9
2	A2 - B1 - C1 - D2	3,7
2	A2 - B3 - C1 - D2	3,7
4	A1 - B3 - C1 - D2	2,8
4	A2 - B3 - C2 - D2	2,8
6	A1 - B3 - C2 - D2	2,5
7	A1 - B3 - C1 - D1	2,1

Ranking of consistent concepts

Figure 2. Extended compatibility matrix and derived ranking of concepts

5 CONCLUSION AND OUTLOOK

The exposed approach shows that design structure matrices can be used to support the selection of an overall product concept during early design phases. It offers a structured and computer supported proceeding to derive a ranking order of consistent concepts from a given number of (partial)solutions. It allows for dealing with large numbers of theoretical alternative solutions and relieves the identification of one or more promising concept(s).

The next step will be the application of the approach in different research projects. Up to now there was only an example application with a relative small morphological matrix. The results approved the working of the approach with real data. In the future it will be applied to much bigger matrices. Thereby it has to be analyzed which combination of evaluation methods, assessing values and value functions for the weights leads to an optimal result. Another open issue is the implementation of tools to support setting up and interpreting the used matrices. Furthermore the approach can be transferred to other domains such as the identification of capable consistent scenarios in scenario technique. An application for the selection of working structures seems promising as well.

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MANAGE COMPLEX SYSTEMS FOLLOW THE FLOW OF INFORMATION!

10TH INTERNATIONAL DSM CONFERENCE

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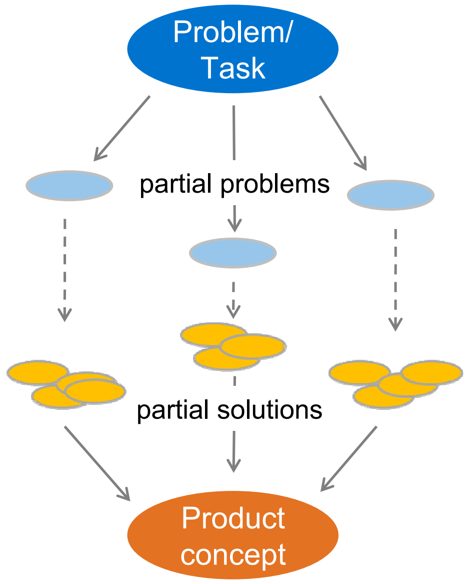
Index

- Introduction and Motivation
- Basis and Related Research
- Approach and Objectives
- Identification of consistent concepts
- Extended compatibility matrix
- Example application
- Future work
- Conclusions

Technische Universität München

Introduction: Conceptual Design



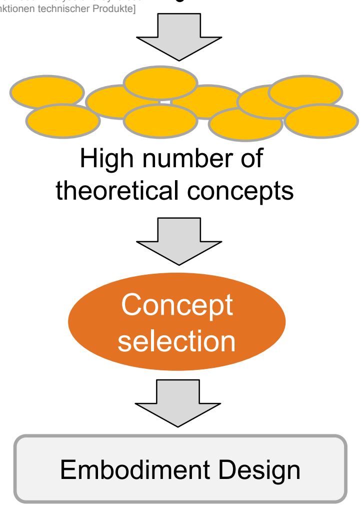
Conceptual Design phase:

- Main result:
  Definition of product concept
- Method of factorization often used to achieve manageable system
- Problem divided into sub problems
- Creation of a large field of partial solutions
- Often usage of a morphological matrix to get an overview of the complete solution field
- Decision has multiple effects on complete following development process

Handling a high number of alternative concepts

Partial functions	Partial solutions 1	2	3	4
T_A	A_1	A_2		
T_B	B_1	B_2	B3	
T_C	C_1	C_2	C_3	C_4
T_D	D_1	D_2		

[Birkhofer 1980: Analyse und Synthese der Funktionen technischer Produkte]



- In a morphological matrix new concepts are generated by combination of different partial solutions
- A small number of functions and solutions leads to high number of theoretical concepts
- Many of these theoretical concepts are unfeasible
- Revision of all combinations is much too extensive

→ Identification of consistent and promising concepts

Basis and related research

Compatibility matrix

		A		B			C				D	
		1	2	1	2	3	1	2	3	4	1	2
A	1			●	●				●			
	2										●	
B	1							●				
	2							●		●		●
	3											
C	1											
	2											
	3										●	
	4											
D	1											
	2											

● Incompatible
☐ Compatible

[Ponn, Lindemann 2008: Konzeptentwicklung und Gestaltung technischer Produkte]

- Different approaches to reduce the high number of alternatives
  - Adoption of the matrix
  - **Integration of evaluation methods**
- Common method: **Compatibility matrix**
- Inconsistencies are marked (geometric, energetic, …)
- Completely symmetrical
- Concentration on pair wise evaluation
- Difficult to manipulate results

Objectives and Approach

Objectives

- Support of concept selection in case of large matrices
- Handle a high number of theoretical concepts
- Automated identification of consistent and promising concepts
- Systematic and structured procedure
- Possibility of computerized tool support
- Comprehensible presentation of results

Approach

- Interdependencies among partial solutions can be represented in a DSM
- The compatibility matrix shows impossible combinations of solutions
- To recognize consistent combinations, all possible connections between the different elements have to be identified and represented in a DSM
- This matrix can be derived from a given compatibility matrix
- Consistent concepts can be identified by a cluster analysis

Adaption of compatibility matrix

	A1	A2	B1	B2	B3	C1	C2	C3	D1	D2
A1			X	X				X		
A2								X	X	
B1							X	X		
B2							X			X
B3										
C1										
C2										
C3									X	
D1										
D2										

Classic compatibility matrix

Compatibility DSM
("Consistency DSM")

	A1	A2	B1	B2	B3	C1	C2	C3	D1	D2
A1					X	X	X		X	X
A2			X	X	X	X	X			X
B1						X			X	X
B2						X		X	X	
B3						X	X	X	X	X
C1									X	X
C2									X	X
C3										X
D1										
D2										

- Classic compatibility matrix shows inconsistencies among solutions
- In the proposed compatibility DSM possible combinations are marked ("Consistency DSM")
- Completely symmetrical
- Matrix can be derived out of classic representation automatically
- „Negative / inverted" image of the classic matrix

Identification of consistent concepts

	A1	A2	B1	B2	B3	C1	C2	C3	D1	D2
A1					X	X	X		X	X
A2			X	X	X	X	X			X
B1						X			X	X
B2						X		X	X	
B3						X	X	X	X	X
C1									X	X
C2									X	X
C3										X
D1										
D2										

Compatibility DSM

Cluster analysis

Completly interlinked clusters
A1 - B3 - C2 - D1
A1 - B3 - C2 - D2
A1 - B3 - C1 - D1
A1 - B3 - C1 - D2
A2 - B1 - C1 - D2
A2 - B3 - C1 - D2
A2 - B3 - C2 - D2

List of consistent concepts

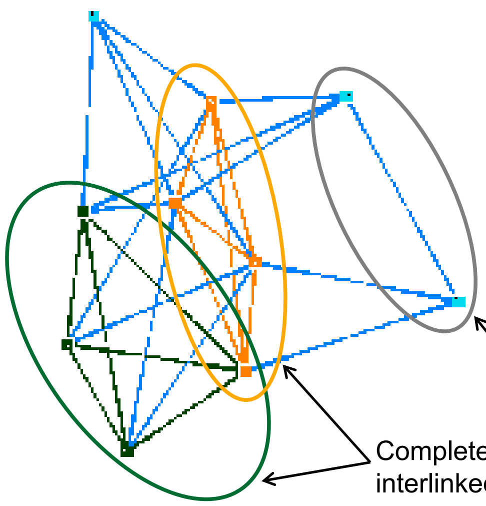
Prerequisites of a consistent concept:

- All selected partial solutions have to be compatible to each other
- Every partial function has to be fulfilled

→ Consistent solutions are represented by completely interlinked clusters
→ Size of the cluster has to match the number of partial functions

Graphical Representation

- Strength based graph
- Easy identification of not used elements/solutions
- Highly compatible elements arranged in the center
- Identification of solutions contained in different concepts (overlapping of clusters)



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B3						0.1	0.3	1.0	0.3	1.0
C1									0.3	1.0
C2									1.0	0.3
C3										1.0
D1										
D2										

<u>High weighting factor</u>:
Positive effects on each other

<u>Low weighting factor</u>:
Compatible, no or small positive influence

- Number of identified possible concepts still too high in most cases
- Reduction to a manageable number for further treatment

→ Identification of most promising concepts

→ Integration of weight factors which indicate positive effects among two partial solutions

→ Extended compatibility matrix

Ranking of consistent concepts

	A1	A2	B1	B2	B3	C1	C2	C3	D1	D2
A1					0.3	0.1	0.3		1.0	0.3
A2			0.1	0.5	0.1	0.5	0.1			1.0
B1						0.1			1.0	1.0
B2						0.5		1.0	1.0	
B3						0.1	0.3	1.0	0.3	1.0
C1									0.3	1.0
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Extended compatibility matrix

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6	A1 - B3 - C2 - D2	2,5
7	A1 - B3 - C1 - D1	2,1

Ranking order

- Weighting factors can be used to gain a ranking order
- All possible and complete concepts consist of the same number of elements and connections
- High weighting factor indicates positive influence

→ Sum of weighting factors is an indicator for the concept quality
→ Automated identification of promising concepts

Example application

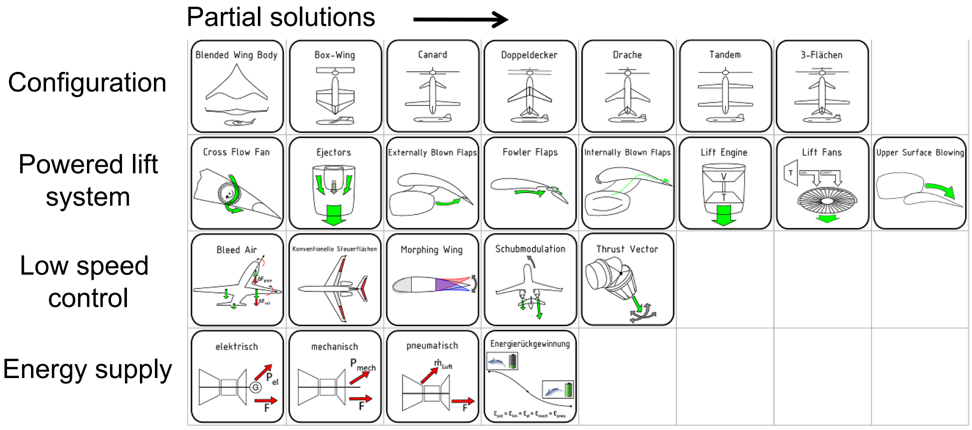
Bauhaus Luftfahrt

Produktentwicklung
Product Development

- Cooperation between Product Development and Bauhaus Luftfahrt e.V.
- Aviation industry
- Early concept phase
- Embedded in project “HyLiner-R”
- Search for ESTOL configuration (Extreme Short Takeoff and Landing)

Created morphological matrix

- Four partial functions
- A total number of 24 partial solutions
- Number of theoretical concepts: 1120



Identification of consistent concepts

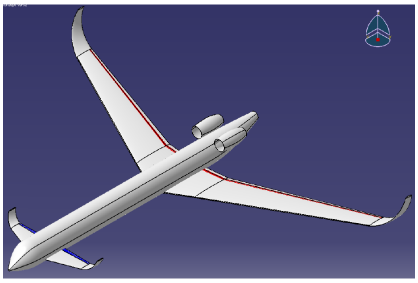
- Pair wise evaluation of all partial solutions
- Interdisciplinary team
- Unclear combinations are marked (“?”), but not taken into further considerations

		Konfiguration							Low Speed Control					Energiebereitstellung für High Lift Devices			
		BWB - Blended Wing Body	Box-Wing / Strutbraced / Joint Wing	Canard / Ente	Doppeldecker	Drachen	Tandemflügel	3 Flächen Flugzeug	Bleed Air	Konventionelle Steuerflächen	Morphing Wing / Winglet	Schubmodulation	Thrust Vector	elektrisch	mechanisch	pneumatisch	Energierückgewinnung
Hochauftriebshilfen	Cross Flow Fan	1	x	1	x	1	x	1	1	1	x	?	1	1	1	1	1
	Ejector	?	x	x	x	1	x	1	1	?	x	?	1	x	x	1	x
	Externally Blown Flaps	?	?	1	1	1	?	3	1	1	1	?	x	x	x	1	x
	Fowler	?	?	1	1	1	?	3	1	1	1	?	1	x	x	x	x
	Internally Blown Flap / Adv. Int. Blown Flap	?	?	1	1	1	?	3	x	3	3	?	1	1	1	1	x
	Lift-Engines	1	1	x	1	1	x	x	1	1	1	?	1	x	x	x	x
	Lift-Fans	1	x	1	x	1	x	x	x	1	1	?	1	1	1	1	1
	Upper Surface Blowing / Coanda Effekt	?	1	1	1	1	1	3	1	1	3	?	x	x	x	1	x

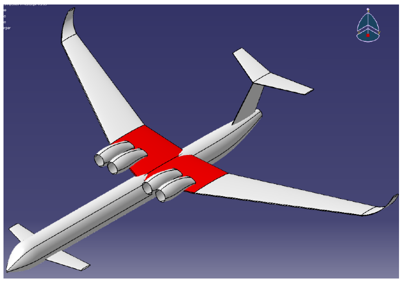
Compatibility DSM (detail)

Selection of two concepts

- Cluster analysis shows 59 consistent concepts
- Evaluation of the used technologies (expert interviews)
- Deduction of two basic concepts
  - Futuristic
  - Realistic



Futuristic concept



Realistic concept

Future Work

- Application to different research projects
  - Development of mechatronic systems
  - Automotive industry
- Analysis of evaluation methods
  - Criteria for measurement of positive influence
  - Adequate weighting functions (linear, logarithmic, …)
  - Range of weighting factor
- Implementation of tool support
  - Assistance for setting up the (extended) compatibility matrix
  - Automated calculation of the ranking order
  - Comprehensible presentation of (intermediate) results
- Further analysis of the graphical representation

Conclusions

- During the conceptual design phase, a large number of alternative concepts has to be reduced to a manageable number
- The well introduced classic compatibility matrix can be adopted to support this task even in case of large morphological matrices
- In the presented approach a compatibility DSM ("Consistency DSM") is used to identify consistent concepts
- This matrix is a "inverted/negative image" of the classic matrix
- Graphical analysis in form of strength based graphs are possible
- The extended compatibility matrix with weighting factors allows for the calculation of a ranking order of consistent concepts
- First experiences with a small morphological matrix are very promising
- Scenario technique and identification of working structures are also possible fields of application