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THE MULTIPLE-DOMAIN-APPROACH AND COST ATTRIBUTES

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Keywords: multiple-domain matrix, domain mapping matrix, design structure matrix, target costing

1 INTRODUCTION

The design structure matrix (DSM) was developed to deal with complex design situations as they occur during product development [3, 4]. Generally a DSM focuses on one aspect of the situation only [2]; however, in realistic use cases many aspects like parts, functions, requirements, or processes interact with each other. To model these interactions and to map between the different domains (aspects) the Multiple-Domain-Matrix (MDM) can be applied [2].

So far, the MDM focussed on the structural properties of the modelled domains. Additional data such as cost estimations or the planned number of variants have not been considered. Furthermore, different structures within the same domain (describing different relation types e.g. within components) have not been compared until now. As there is no framework which allows the comparisons of single relations, hardly any results beyond the structural view can be obtained from matrix-based analysis approaches [1, 2].

In this contribution we present a method to include additional data into the MDM in order to allow further analyses and interpretations. We propose to include cost estimations obtained by target costing.

2 METHODOLOGY

First the computations proposed by the MDM [2] were analyzed. The focus is set on the structural and numerical properties of the computations. Next, examples of the different types of computations were collected and examined. Then specific data types which augment the different domains were collected and their significances for the computable structures were determined. Based on this the formulas of the MDM computations were extended. The additional data had to be transformed to be applicable to the extended formulas. The extension must not change the resulting structures and has to consider additional aspects of the data types. Finally the resulting values were analyzes and their significance in the context of the data types was investigated.

3 RESULTS

The results will be discussed using a slightly altered example from [5]: a turbine transmission that consists of a housing, a gear, a pinion and several other parts. The parts fulfil several functions such as magnify torque or seal transmission (see figure 1a for details). In [5] the example serves for demonstrating the mapping of cost estimations between functions and parts.

The matrix can be used to compute a network that links two parts if they fulfil a function together. The standard formula for this computation is given by equation (1). This computation focuses on the structural constellation only and does not consider numerical aspects. Among these aspects is the contribution of a part to the fulfilment of a function. It is possible that the degree of fulfilment differs between two parts that contribute to the same function.

$$DSM = DMM^{T} \cdot DMM \tag{1}$$

Another aspect is the relevance of specific functions to the entire functionality. As those aspects are not considered by the conventional MDM computation (equation (1)) a relation's importance can only be determined in the context of all other relations. As all relations have no other significance than their existence they only gain importance when working together. Thus it is not possible to identify those relations between two parts which are important for the overall functionality during product development.

In order to consider the two aspects mentioned above they have to be modelled and integrated into the computation: A part's significance to a function can be modelled by the part's proportion of the function's fulfilment. The percentage is included into the computation by weighing the domain-mapping matrix which describes the mapping between functions and parts. The resulting matrix for this example is given in figure 1a. With this new matrix another network can be computed by equation (1). This network's relations can already be compared. The computed values equal the relations' significance for function fulfilment. However the functions are still considered to be equally important.

	Cast housing	Gear	Pinion, shaft	Gear shaft	Gear bearings	Pinion bearings	Covers with seals	Piping
Magnify torque	0%	65%	35%	0%	0%	0%	0%	0%
Transfer torque	0%	0%	30%	70%	0%	0%	0%	0%
Support gears	45%	0%	10%	20%	15%	10%	0%	0%
Seal transmission	85%	0%	0%	0%	0%	0%	15%	0%
Lubricate transmission	0%	0%	0%	0%	0%	0%	0%	100%

a)

	Magnify torque	Transfer torque	Support gears	Seal transmission	Lubricate transmission
Magnify torque	33,0	0,0	0,0	0,0	0,0
Transfer torque	0,0	8,0	0,0	0,0	0,0
Support gears	0,0	0,0	29,0	0,0	0,0
Seal transmission	0,0	0,0	0,0	10,0	0,0
Lubricate transmission	0,0	0,0	0,0	0,0	1,0

b)

Figure 1. Example data: a) weighted DMM, b) diagonal matrix containing the function target osts

One possibility to model a function's importance is assigning them target costs. The total target costs are split among all functions according to the functions' significance. These cost attributes cannot be integrated as easily as the part significance: Two requirements exist when considering costs. The first one applies to all attributes. The integration of an attribute must not change the resulting network. Otherwise all structural analyses would be obsolete as soon as attributes are considered. The second requirement applies specifically to costs. The costs must remain consistent i.e. the total sum of all costs must remain identical in all considerations. Both requirements are fulfilled if the costs are modelled as a diagonal matrix (figure 1b). However this matrix has to be included in the computation. The new formula is given in equation (2).

	Cast housing	Gear	Pinion, shaft	Gear shaft	Gear bearings	Pinion bearings	Covers with seals	Piping
Cast housing	2	0	1	1	1	1	1	0
Gear	0	1	1	0	0	0	0	0
Pinion, shaft	1	1	3	2	1	1	0	0
Gear shaft	1	0	2	2	1	1	0	0
Gear bearings	1	0	1	1	1	1	0	0
Pinion bearings	1	0	1	1	1	1	0	0
Covers with seals	1	0	0	0	0	0	1	0
Piping	0	0	0	0	0	0	0	1

a)

	Cast housing	Gear	Pinion, shaft	Gear shaft	Gear bearings	Pinion bearings	Covers with seals	Piping
Cast housing	13,1	0,0	1,3	2,6	2,0	1,3	1,3	0,0
Gear	0,0	13,9	7,5	0,0	0,0	0,0	0,0	0,0
Pinion, shaft	1,3	7,5	5,1	2,3	0,4	0,3	0,0	0,0
Gear shaft	2,6	0,0	2,3	5,1	0,9	0,6	0,0	0,0
Gear bearings	2,0	0,0	0,4	0,9	0,7	0,4	0,0	0,0
Pinion bearings	1,3	0,0	0,3	0,6	0,4	0,3	0,0	0,0
Covers with seals	1,3	0,0	0,0	0,0	0,0	0,0	0,2	0,0
Piping	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0

b)

Figure 2. Resulting Matrices: a) computed from the binary DMM by formula (1), b) computed from the weighted DMM and the function target costs by formula (2)

As figure 2b shows the structure of the resulting matrix has not changed. The interpretation of the values has changed though. Now the values equal the relations' shares of the total costs. Now the relations' importance is given by their values and they can be compared without referring to all relations. By comparing the relations among each other the important relations can be determined. Thus it is possible to focus on them when designing the transmission.

$$DSM = DMM^{T} \cdot DIAG \cdot DMM \tag{2}$$

4 CONCLUSION

The standard MDM computation focuses on the structural properties of the resulting network and allows for structural analyses only. Consequently, it is hardly possible to determine a relation's significance for the entire system in itself.

To determine a relation's significance two additional aspects have to be integrated into the MDM computation. First, a part's importance to function fulfilment has to be modelled. Weighing the DMM allows modelling this aspect. Second, the function's importance to the overall system has to be modelled. The importance relates to the function's target cost. By modelling the costs as a diagonal matrix they can be integrated into the computation without changing the structure of the resulting matrix. If the structure was changed by the attributes all structural analyses would be obsolete.

The resulting network offers new possibilities for analyses. As the sum of all weights equals the total target costs each weight is a measurement for the relation's importance. As all weights refer to the same total costs, comparisons among the relations are possible. Moreover, even comparisons between relations and parts become possible. Both weights refer to the total targets costs and the cost sum is not consistent if one weight type is not considered. Thus, it is possible to identify important relations and focus on them during product development.

A new analysis becomes possible as a row sum of the resulting matrix equals the corresponding part's target cost. In the resulting matrix these costs are split into costs for the part itself, and into costs for its relations to other parts. The target costs of a part should correspond to time spent designing and optimizing the part during product development. Now, the target costs can be split into target costs of the part itself and into target costs of the relations to other parts. Thus, it is possible to split the design time into time for designing the part itself and into time for designing the interactions with other parts.

By integrating new aspects into the MDM the analysis possibilities could be enhanced; subsequently more and better analysis results can be achieved. Future work will focus on other types of networks like organisations or processes and on other MDM computations.

REFERENCES

[1] Biedermann W. *Attribute für MDM-Matrizen,* 2007 (Diploma Thesis, TU München).

[2] Maurer M. *Structural Awareness in Complex Product Design,* 2007 (Dissertation, TU München).

[3] Browning T. R. Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions *IEEE Transactions on Engineering Management*, 2001, 48(3), pp. 292-306.

[4] Kusiak A. *Engineering Design: Products, Processes and Systems*, 1999 (Academic Press, San Diego).

[5] Ehrlenspiel K., Kiewert A. and Lindemann U. *Cost-Efficient Design*, 2007 (Springer, Berlin).

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The Multi-Domain-Approach and Cost Attributes

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Introduction

Initial situation

- The multi-domain-computation focuses on structural system aspects

Extending the multi-domain-computations

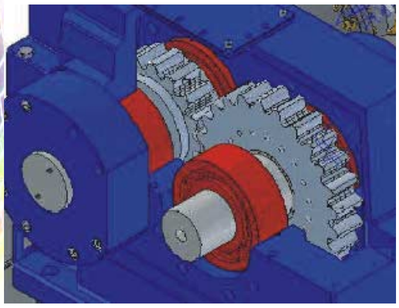
- Additional aspects like the importance of one relation can be modelled in the network itself
- Element attributes can be integrated into the multi-domain to model the element’s specific significance
- Specific characteristics of the attribute types have to be considered otherwise the resulting value cannot be interpreted

Resulting possibilities

- Attributes allow the specification of a relation beyond its structural significance (weight, cost etc.)
- This allows focusing on these important relations to improve the overall functionality

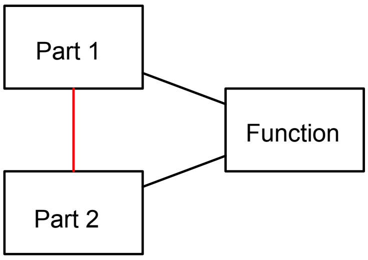
Example system: turbine transmission

- The transmission consists of different parts
- The parts fulfill different function
- A part network due to function fulfillment can be computed
- How can the significance of an relation between two parts be determined?



	Cast housing	Gear	Pinion, shaft	Gear shaft	Gear bearings	Pinion bearings	Covers with seals	Piping
Magnify torque	0	1	1	0	0	0	0	0
Transfer torque	0	0	1	1	0	0	0	0
Support gears	1	0	1	1	1	1	0	0
Seal transmission	1	0	0	0	0	0	1	0
ricate transmission	0	0	0	0	0	0	0	1

Standard computation – part network due to function fulfillment



Two parts are linked if they fulfill a function together

$$P = FP^{T} \cdot FP$$

P: Part network
FP: function-part-DMM
(Maurer, Lindemann 2007)

	Cast housing	Gear	Pinion, shaft	Gear shaft	Gear bearings	Pinion bearings	Covers with seals	Piping
Cast housing	2	0	1	1	1	1	1	0
Gear	0	1	1	0	0	0	0	0
Pinion, shaft	1	1	3	2	1	1	0	0
Gear shaft	1	0	2	2	1	1	0	0
Gear bearings	1	0	1	1	1	1	0	0
Pinion bearings	1	0	1	1	1	1	0	0
Covers with seals	1	0	0	0	0	0	1	0
Piping	0	0	0	0	0	0	0	1

Characteristics of the standard computation

Characteristics of the standard computation

- Focus on structural aspects
- No consideration of numerical aspects
- Interpretation of values: number of functions fulfilled by both parts

Not considered aspects

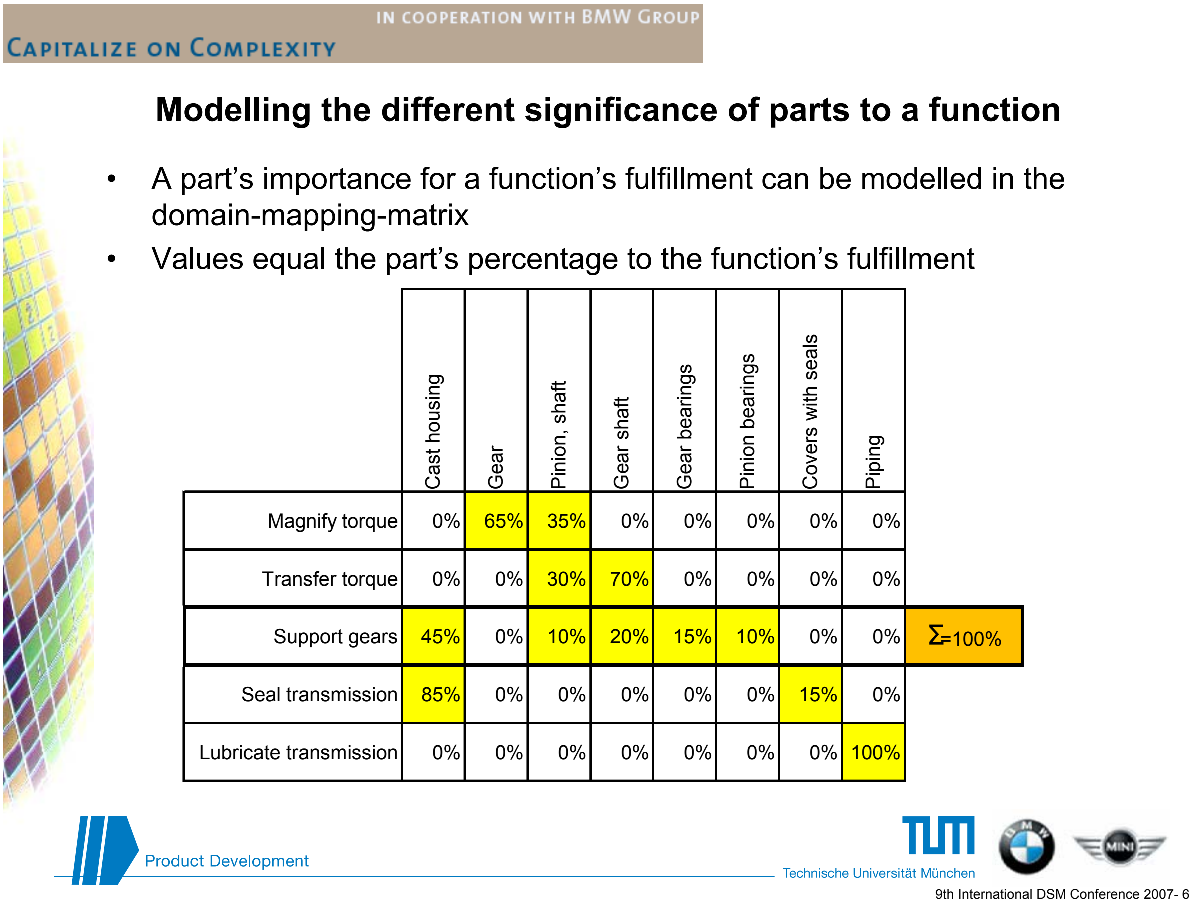
- Contribution of parts to the fulfillment of functions
- Relevance of specific functions for the entire functionality and intention

Resulting deficiencies of conventional computations

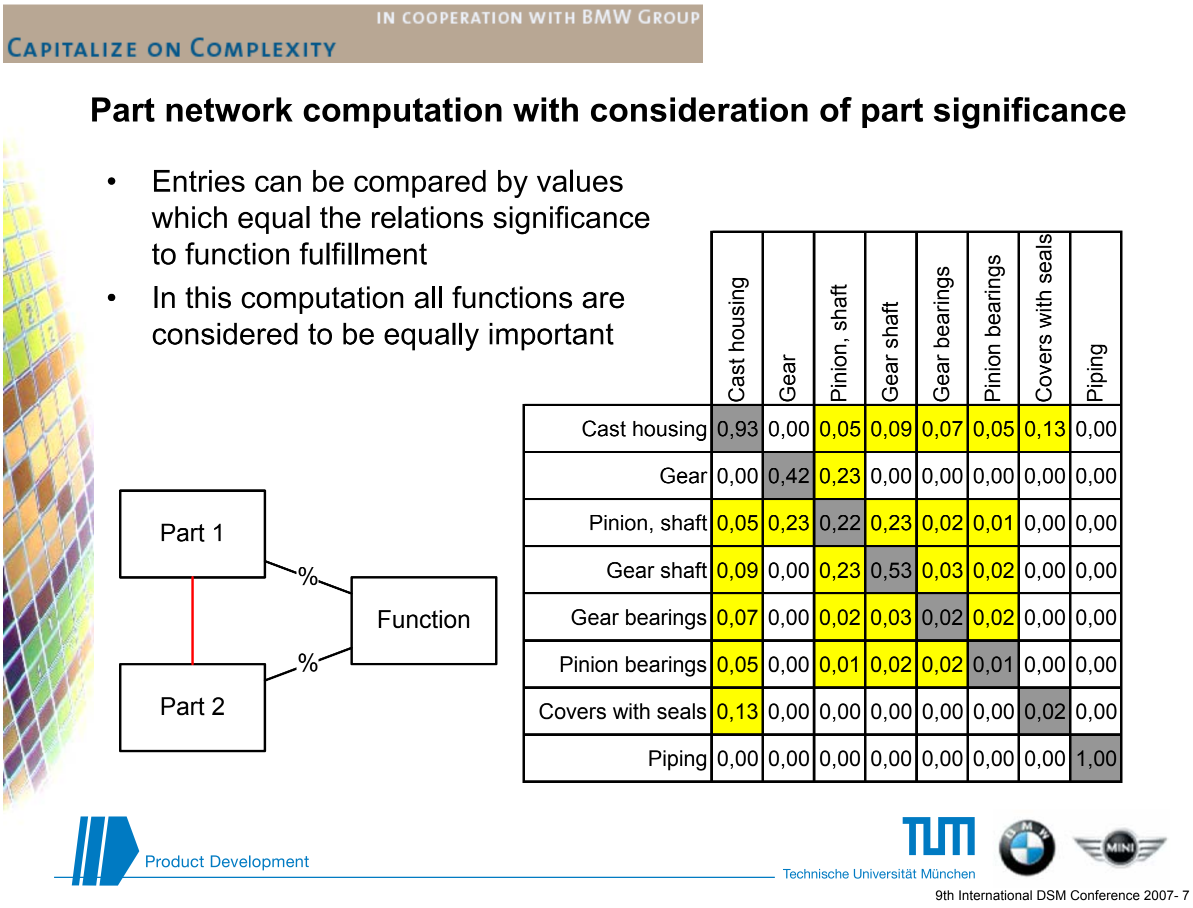
- A relation's importance can only be determined in the context of all other relations
- The significance of single relations cannot be determined

Modelling the different significance of parts to a function

- A part's importance for a function's fulfillment can be modelled in the domain-mapping-matrix
- Values equal the part's percentage to the function's fulfillment



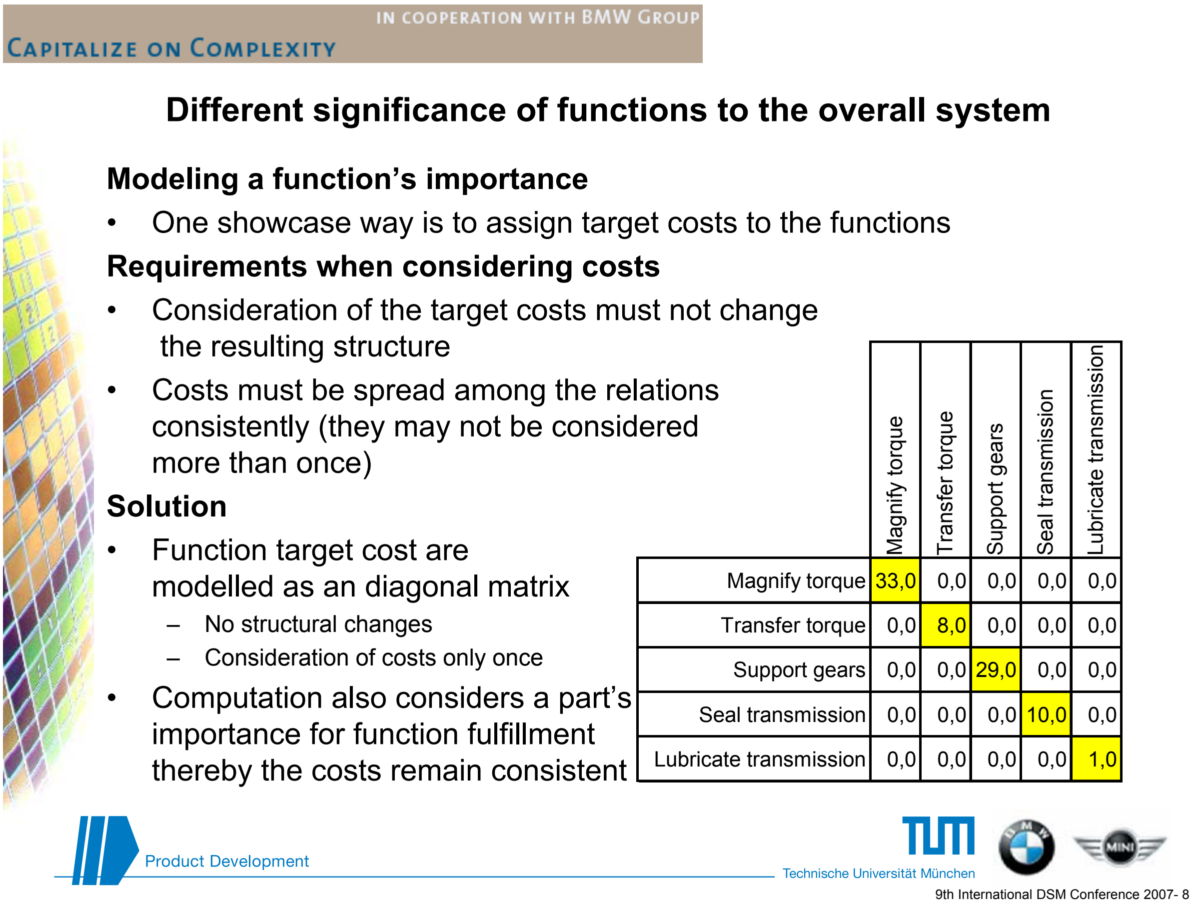
	Cast housing	Gear	Pinion, shaft	Gear shaft	Gear bearings	Pinion bearings	Covers with seals	Piping	
Magnify torque	0%	65%	35%	0%	0%	0%	0%	0%	
Transfer torque	0%	0%	30%	70%	0%	0%	0%	0%	
Support gears	45%	0%	10%	20%	15%	10%	0%	0%	Σ=100%
Seal transmission	85%	0%	0%	0%	0%	0%	15%	0%	
Lubricate transmission	0%	0%	0%	0%	0%	0%	0%	100%	



Part network computation with consideration of part significance

- Entries can be compared by values which equal the relations significance to function fulfillment
- In this computation all functions are considered to be equally important

	Cast housing	Gear	Pinion, shaft	Gear shaft	Gear bearings	Pinion bearings	Covers with seals	Piping
Cast housing	0,93	0,00	0,05	0,09	0,07	0,05	0,13	0,00
Gear	0,00	0,42	0,23	0,00	0,00	0,00	0,00	0,00
Pinion, shaft	0,05	0,23	0,22	0,23	0,02	0,01	0,00	0,00
Gear shaft	0,09	0,00	0,23	0,53	0,03	0,02	0,00	0,00
Gear bearings	0,07	0,00	0,02	0,03	0,02	0,02	0,00	0,00
Pinion bearings	0,05	0,00	0,01	0,02	0,02	0,01	0,00	0,00
Covers with seals	0,13	0,00	0,00	0,00	0,00	0,00	0,02	0,00
Piping	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00



Different significance of functions to the overall system

Modeling a function's importance

- One showcase way is to assign target costs to the functions

Requirements when considering costs

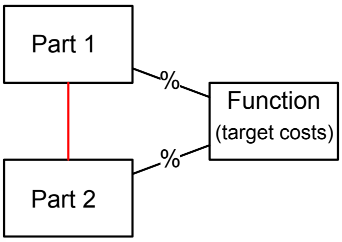
- Consideration of the target costs must not change the resulting structure
- Costs must be spread among the relations consistently (they may not be considered more than once)

Solution

- Function target cost are modelled as an diagonal matrix
  - No structural changes
  - Consideration of costs only once
- Computation also considers a part's importance for function fulfillment thereby the costs remain consistent

	Magnify torque	Transfer torque	Support gears	Seal transmission	Lubricate transmission
Magnify torque	33,0	0,0	0,0	0,0	0,0
Transfer torque	0,0	8,0	0,0	0,0	0,0
Support gears	0,0	0,0	29,0	0,0	0,0
Seal transmission	0,0	0,0	0,0	10,0	0,0
Lubricate transmission	0,0	0,0	0,0	0,0	1,0

Computation with consideration of part and function significance



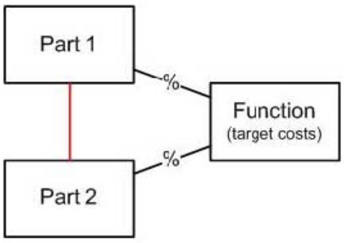
$$P = FP^T \cdot C \cdot FP$$

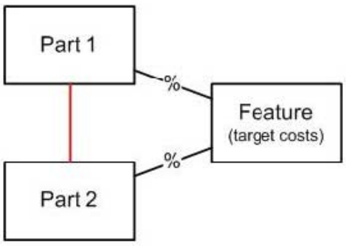
P: Part network
FP: function-part-DMM
C: diagonal cost matrix

	Cast housing	Gear	Pinion, shaft	Gear shaft	Gear bearings	Pinion bearings	Covers with seals	Piping	
Cast housing	13,1	0,0	1,3	2,6	2,0	1,3	1,3	0,0	
Gear	0,0	13,9	7,5	0,0	0,0	0,0	0,0	0,0	
Pinion, shaft	1,3	7,5	5,1	2,3	0,4	0,3	0,0	0,0	Σ= 16,9
Gear shaft	2,6	0,0	2,3	5,1	0,9	0,6	0,0	0,0	
Gear bearings	2,0	0,0	0,4	0,9	0,7	0,4	0,0	0,0	
Pinion bearings	1,3	0,0	0,3	0,6	0,4	0,3	0,0	0,0	
Covers with seals	1,3	0,0	0,0	0,0	0,0	0,0	0,2	0,0	
Piping	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	
									Σ= 81,0

Characteristics of the enhanced computation

- The total costs are spread among all relations elements
- A more important relation has a higher cost value
- Relations and elements can be compared concerning their cost values
- It is possible to decide if a focus on the parts or focus on the interaction of parts is sensible during product development
- It is also possible to decide on which interaction the development should focus
- Comparison between different networks are possible if the same costs were spread among their relations during the computation





Conclusion

Properties of the standard computation

- Focus on structural properties
- No modeling and consideration of non-structural content

Modeling of additional aspects

- Part significance modeled by a weighted DMM
- Function significance modeled by target costs
- Integration of a diagonal matrix does not change the resulting structure

New possibilities

- Finding the important relations to focus on them
- Comparing relations and elements to decide which is more important
- Comparing different networks