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Product Family Concept Evaluation

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Abstract
Market globalisation leads to tight segmentation of both product functions and product client base. Neither standard nor specialized products can no longer fulfil market needs and requirements. This leads to employment of modular product principles, which can better meet customer demands and company's internal goals.
Design of new products is a complicated process. Products must comply with many requirements. Often these requirements contradict with one another. In certain situations fulfilling specific requirements may be impossible. The faster and cheaper product can be delivered to market, the more profitable it is to the manufacturer. Several methods and tools have been developed to achieve this goal. Some of these methods are based on information technology like formation of product families.
The smaller is the quantity of the product, the more expensive will the design process become. Large part of new product cost is determined during the initial/conceptual design phase. It is wise to optimise product/product structure in as early design stage as possible. It is necessary to investigate and evaluate different product variants taking into account time and expenses over the whole product life cycle (design, manufacturing, assembly, sale, service and utilization), simultaneously reducing design costs and time.
During the creation of design-centred product families we have to determine valid boundaries for different concepts, including influence of used technologies and possible use of future ones (possibility of integration).
Changes in concept require investments and therefore it is reasonable to exploit one concept for as long as possible.
The purpose of this paper is to investigate the determination of validity of concept boundaries of product family and underlying methods.
When we are dealing with large number of parameters, we must determine the most significant ones (Pareto principle) and apply optimisation tools to them.
The use of simulation tools enables virtual analysis of possible variants and hazards. This is especially important in the case of multidisciplinary products (based on mechanics, hydraulics, pneumatics, electricity).
As a practical example we present conceptual analysis of one member of telescopic work platform product family.

Keywords: Concept evaluation, concept boundaries, DSM.

Introduction

Nowadays, the growing demand for customizable or configurable products involves an increasing number of product variants and a growing complexity of products while controlling the product costs and the customer lead-time. This task becomes more difficult when the supply chain layout has a significant influence on operating costs. Consequently, when designing a new product family, a consistent approach is necessary to quickly define a set of product variants and their relevant supply chain, in order to guarantee the customer satisfaction and to minimize the total operating cost of the global supply chain [1].

The conceptual design stage mainly consists of concept generation and concept evaluation. The goal of concept generation is to come up with a large number of very different product ideas. The more concepts generated in this step, the more likely it is that one or two will pass the subsequent concept evaluation, and progress toward the detailed design phase of the development process. It is found that hundreds of product concepts are usually generated in this stage, of which five to twenty will merit serious consideration [2]. A thorough exploration and evaluation of alternatives early in the design process will surely reduce the changes to be made in later stages, and increase the likelihood of success of the new product projects. Detailed information about alternative product concepts is not normally available, and decisions must be made using qualitative information and judgment [3]. Since the evaluations are not so clear-cut, expert knowledge is always required to direct the evaluation towards specific decisions. There are two common problems in the concept generation and evaluation, namely: inadequate exploration of all the feasible alternative concepts, and ineffective integration of product design with evaluation criteria such as ease of manufacture and production costs. Due to the constraints of time and resources, as well as the limited expertise available in an organization, designers are used to considering only one or two alternatives. This procedure always results in a situation where a superior concept appears in the subsequent stages, but it is too late or too costly to implement it [4].

The problem how to evaluate concept boundaries of product family in early stage of product development is studied in this paper.

As an example the case of telescopic work platform product family development is considered.

Manufacturer has been in lifting platform market for five years. Their product portfolio includes trailer mounted scissor lifts and boom lifts but there was no telescopic work platform. Company started telescopic work platform development to enter in the new market segment. Telescopic work platform main advantage for boom lift is shorter transport length. But it has several disadvantages: higher complexity, smaller stiffness and higher mass.

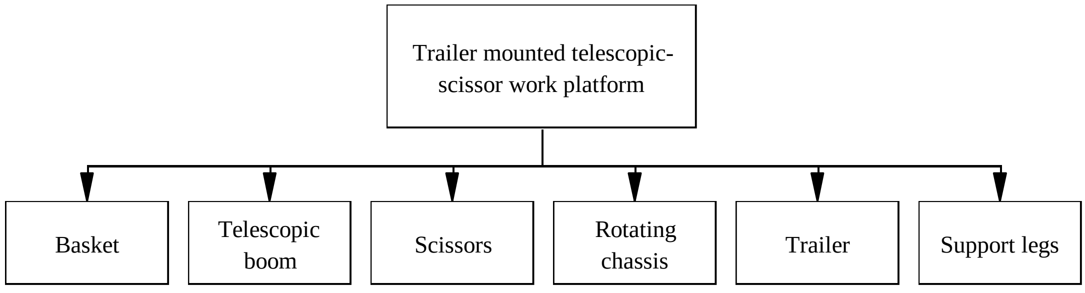

Figure 1 Main modules of work platform product family

The market of trailer mounted work platforms is well developed and quite full. To compete in such a market one must offer something innovative. After market analyses

the firm proposed that their new work platform transport length must be much shorter than those currently available in market. In addition the new telescopic boom lift should be able to carry full load (230 kg) in full working area and overall mass should be near 2500 kg. The market analyses showed that the newer and most demanded telescopic work platforms are with scissor mechanism. The company proposed the telescopic work platform to be designed as product family.
Such kind of demands/wishes caused several problems. The first serious problem was to evaluate selected concept boundaries. Is it possible to follow all the design criteria with selected concept?
The concept, which was chosen for new work platform, is shown in Fig.2 and Fig.3.

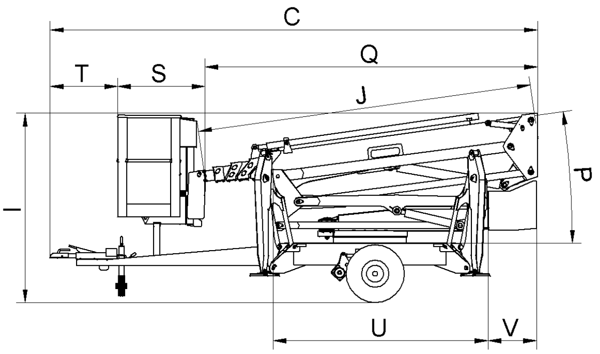

Figure 2 Telescopic work platform in transport position

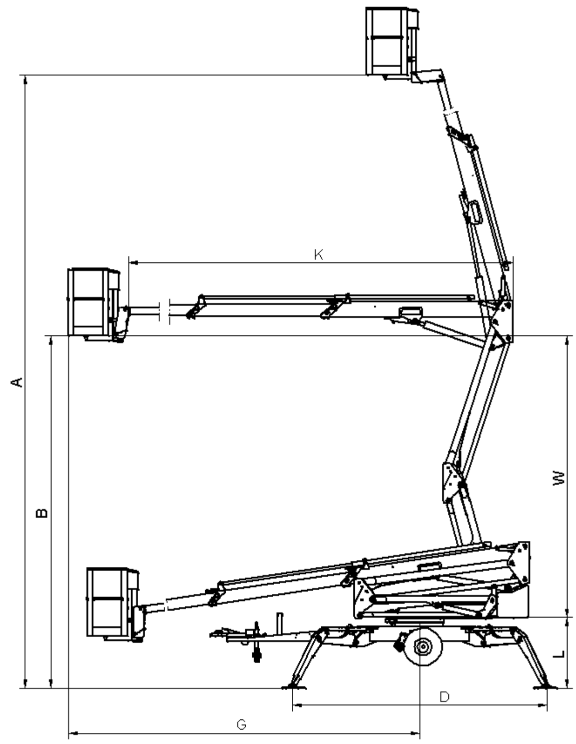

Figure 3 Telescopic work platform in working position

Geometrical boundaries of concept

Telescopic work platform concept with specific dimensions is depicted in Fig. 2 and Fig. 3

Question is what would be the maximum lifting height if the transportation length C is given.

From Fig.2 is easy to see that lifting construction/equipment length in transport position can be found as follows Q=C-T-S, where T is necessary length to ensure manoeuvrability and S is length of basket and basket fastening. The maximum length of telescopic boom in transport position can be J=Q/cosP. Since the angel P is small then the $\cos P \approx 1$ and J is equal to Q. The question is how many boom segments is it rational to make. The number of boom segments is constrained by two criteria in addition to lifting height:

1. boom segments overlap, segments protrusion from each other in boom closed position and maximum length in closed position;
2. boom segments cross-section height and lift transportation height.

There are hydraulic hoses and electric cables inside the telescopic boom therefore the smallest boom cross-section height cannot be smaller than C_{Hmin}. Hydraulic cylinder and chains are used for telescopic boom drive. Chains are fixed at the end of each boom segment therefore boom segments must be protruded from each other by length C_L. Because in between the boom segments there are chains then every next boom segment cross-section must be higher than the previous one by C_N. If the telescopic boom cross-section maximum height can be C_{Hmax} then maximum number of boom segment can be calculated as follows $n_{max}=(C_{Hmax} - C_{Hmin})/C_N + 2$, and rounded down to nearest integer. If the number of segments of telescopic boom (n_s) is known then the length of one segment can be calculated as $L_s= J -(n_s-1)*C_L$.
To find out the maximum length of the telescopic boom, it must be noted that when the boom is fully opened the boom segments are overlapped by length C_P. The maximum length of boom is $L_{Bmax} =Ls + (n_s-1)*(L_s - C_p)$.
To determine the maximum lifting height of the work platform it is also necessary to determine scissors lifting height. It is obvious from Fig. 2 that maximum lifting height for scissors measured from support structure is W=Q+U=2*Q-V. When support legs are streched out the support structure is elevated by L from the ground. The overall lifting height can be calculated as follows $A=L+W+L_{Bmax1}$. From here it can be concluded that such an approach is not very useful, because to determine the overall lifting height of the concept it is necessary at first to determine eight different parameters. These parameters can be determined after more detailed design process. Even though if these parameters could be determined and result calculated, one must not trust this number very much because this represents geometrically/theoretically possible lifting height. The mass and stability constraints were not considered. Economical and technological constraints were neglected. Therefore this is quite theoretical boundary and is not practically usable.
Some better method for determining boundaries is needed. It should include technological and mass properties. Moreover it should be fast and easy to use. Methodology where market research results are used to evaluate concept boundaries is presented in this paper.

Evaluating concept using market research

Market research gives overview of currently available products and their specifications. This allows us to position products in the market more accurately. In the other hand we can also get useful information from market research.
Some assumptions must be made for using market research information:

- new product and those currently available in market have nearly the same concept;
- materials used for new product are the same as used in currently available products;

- the best of available technologies are used;
- currently available products have been designed by experienced engineers, who may have better know-how than we do.

For effective use of market research, it is necessary to determine the parameters that need to be observed.

In many cases, merely building a Design Structure Matrix (DSM) model provides a useful approach for organizing and visualizing system information. The representation and analysis capabilities of DSM´s contribute to improve system understanding and innovation [5].

There are two main categories of DSM´s: Static and Time-based. Static DSMs represent system elements existing simultaneously, such as components of a product architecture or group in an organization. Static DSMs are usually analysed with clustering algorithms. In time-based DSM´s, the ordering of the rows and columns indicates a flow through time: upstream activities in a process precede downstream activities, and terms like “feedforward” and “feedback” become meaningful when referring to interfaces. Time-based DSM´s are typically analysed using sequencing algorithms [5].

There are four main DSM applications to product developers, project planners, project managers, system engineers, and organizational designers:

1) Component-Based or Architecture DSM: Used for modelling system architectures based on components and/or subsystems and their relationships.
2) Team-Based or Organization DSM: Used for modelling organization structures based on people and/or groups and their interactions.
3) Activity-Based or Schedule DSM: used for modelling process and activity networks based on activities and their information flow and other dependencies.
4) Parameter-Based or Low-Level Schedule DSM: Used for modelling low-level relationships between design decisions and parameters, system equations, subroutine parameter exchanges, etc.

Each application classified as either static or time-based [5].

Enterprises benefit a lot, when they recognize, understand, and exploit the relationship between the product architecture (Architecture DSM), organization structure (Organization DSM) and process configuration (Schedule DSM and Low-Level Schedule DSM) [6].

Design structure matrix of telescopic work platform is given in the Table 1.

Parameters acquired with market research can be arranged into groups according to product functions. Restructured DSM is given in table 2.

To investigate concept boundaries it is useful to give most significant parameters by ratios to each another. For example to investigate the telescopic work platform concept boundaries the following parameters (Figure 2, Figure 3) were selected:

- lifting height A;
- lifting outreach in horizontal G;
- transportation length C;
- load in the basket F;
- work platform overall mass E.

These are company’s requested parameters, which were highlighted by DSM matrix. The same list of parameters is presented in product catalogues as well.

Table 1 Design structure matrix of telescopic work platform

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Overall lifting height	A	A		1		2		1			1	2					
Lifting height of scissors	B	2	B	1		1					1	2					
Transport length	C	1	1	C							2						
Support width	D				D			2									
Overall mass	E					E		2									
Lifting capacity	F				1	1	F	2									
Maximum outreach	G				2	1		G									
Transport width	H				2				H					1			
Transport height	I	1	2		1					I			2				
Length of telescopic boom (closed)	J			2		2					J						
Length of telescopic boom (opened)	K	2	1		1	2		2			2	K					
Lifting height of support legs	L	2	1									1	L				
Basket width	M					1								M			
Basket length	N			2		1									N		
Number of workers allowed in basket	O			1				1						2	2	O	
Angle of telescopic boom in transport pos.	P												1				P

Table 2 Restructured DSM

		D	G	E	F	J	C	A	K	B	L	I	N	M	O	H	P
Support width	D	D	2														
Maximum outreach	G	2	G	1													
Overall mass	E		2	E													
Lifting capacity	F	1	2	1	F												
Length of telescopic boom (closed)	J			2		J	2										
Transport length	C					2	C	1		1							
Overall lifting height	A		1	2		1	1	A	2								
Length of telescopic boom (opened)	K	1	2	2		2		2	K	1							
Lifting height of scissors	B			1		1	1	2	2	B							
Lifting height of support legs	L							2	1	1	L						
Transport height	I	1						1		2	2	I					
Basket length	N			1			2						N				
Basket width	M			1										M			
Number of workers allowed in basket	O		1				1						2	2	O		
Transport width	H	2												1		H	
Angle of telescopic boom in transport pos.	P										1						P

It is important to find relationship between work platform lifting height and overall mass. For that descriptive characteristics mH, mU and Ht where found:

mH is load and lifting height multiplication ratio to mass $mH = \frac{A \cdot F}{E}$ (Eq.1);

mU is load and lifting outreach in horizontal multiplication ratio to mass

$$mU = \frac{G \cdot F}{E} \qquad \text{(Eq.2)};$$

Ht is lifting height ratio to transportation length $Ht = \frac{A}{C}$ (Eq.3).

Values of the 15 available work platforms characteristics see Fig. 4

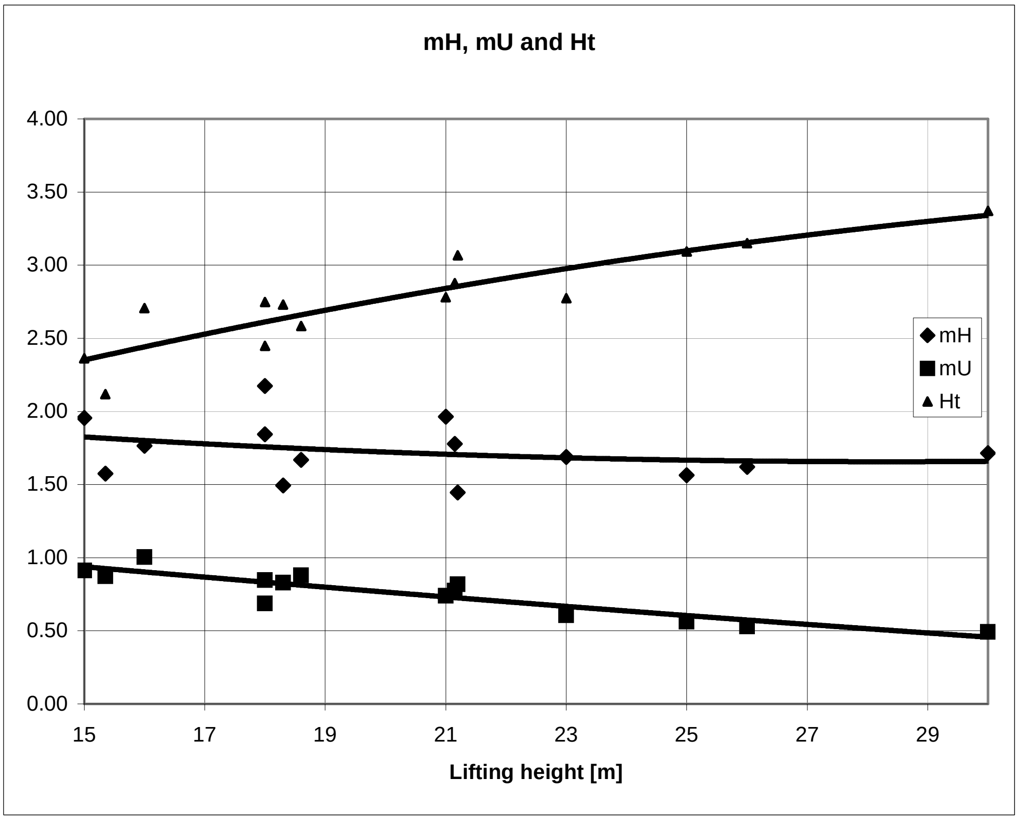

Figure 4 Values mH, mU and Ht of 15 investigated telescopic work platforms

Boundary values calculated in such a way are not absolutely exact, but the accuracy suits with engineering practise. For example some ratios may be technology dependant - if new technology is attainable - this boundary can be stretched. The advantage of using suggested ratios is that all technological aspects, market situation, material properties etc. are considered comprehensively. Disadvantage is that the ratios are based on company specific technology and specific market information.
To verify the correctness of suggested approach and to evaluate concept boundaries the correlation matrix was built, see Table 3.

From correlation matrix follow that:

- Lifting height, mass and transport length are correlating with each other;
- Maximum outreach is correlated with lifting height, with transport length, mass and with support width;
- Mass is strongly correlated with lifting height;
- Support width is correlated more with mass than lifting height and outreach;

Table 3 Correlation matrix of selected parameters of currently available work platforms

	Lifting height	*Transport length*	*Support width*	*Mass*	*Lifting capacity*	*Outreach*
Lifting height	1.00					
Transport length	0.88	1.00				
Support width	0.68	0.64	1.00			
Mass	0.90	0.72	0.81	1.00		
Lifting capacity	-0.40	-0.51	0.00	-0.07	1.00	
Outreach	0.72	0.59	0.64	0.68	-0.54	1.00

On the basis of the market research the best value for mH=2.17 and the best for mU=1.0. Then according to the equations Eq.1 and Eq.2 the maximum lifting height can be 23.6 m and maximum outreach can be 10.9 m. (For the maximum mass of 2500 kg and the lifting capacity of 230 kg)
Some innovation, approx. 200 hours of work and slight concept change were needed to achieve maximum outreach 12.7 m in our case.

Conclusions

Parameters from market research significantly help to evaluate product concept boundaries of product family in early stage of design process.
Necessary expert knowledge to evaluate alternative design concepts could be acquired from market research.
DSM approach helps to select parameters for evaluation of design concepts.

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