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ON USING THE DSM TECHNOLOGY APPROACH TO SYNERGY-BASED DESIGN OF INTERDISCIPLINARY SYSTEMS

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1 Introduction

It is obvious that the integration of different technologies into interdisciplinary systems cannot be treated as their simple summing but as a way of compensating their mutual weaknesses and amplifying the synergy of their integration. But the success of this approach also depends on human factors – the competence and expert knowledge of the design team. In the present paper unique data about start-up shortcomings of two categories of interdisciplinary artefacts: equipment control and factory automation systems are presented. It is shown that most of human and technical shortcomings can be treated as synergy-based. Further a new paradigm for the design of interdisciplinary systems - a synergy based integration of allied technologies is provided. It is shown that the integration of the Design Structure Matrixes technology and the Theory of Design Domains is a suitable basis for this purpose and makes it possible to develop a new family of adaptive design tools. A successful case study of the synergy-based integration of allied technologies is described.

2 Background of the present research

The increase of the integration of different technologies in new products with better performance and marketing power due to the exploitation of the best features of allied technologies has been an ever-growing tendency during the last decades. At the same time the design of interdisciplinary systems is a complicated activity as there is still no suitable design metatool allowing integrating so far different technology-related design tools. Around the beginning of the present century the engineering design research community reached the somewhat confusing conviction that the time of classical prescriptive engineering design methodologies is going to be over. It is obvious that engineering design is not a pure technical problem any more but a complex activity, involving artefacts, people, tools, processes, organisations and conditions of the real economic environment [1;2]. These arguments are especially true for interdisciplinary systems (mechatronic products, lighting devices, etc) where the complicated synergy aspects between allied technologies are added. In the launched race between research groups to fill this gap it seems that one of the possibilities to get out of this situation is to involve a new paradigm – the synergy-based approach to design [3]. The synergy-based approach makes it possible to bring design parameters, market conditions, human factors, reliability problems, etc under one umbrella.

But at first it is necessary to define the concept of "synergy" used in the present context. The term "synergy" is derived from the Greek word *synergeia* that means collaboration. Linguistically the word "synergy" marks the situation when the summary effect of different factors due to their mutual empowering is greater then their sum. Sometimes it is called 2+2=5 effect. The essence of the synergistic approach to interdisciplinary systems design is seen in Fig. 1.

	Unsuitability of allied technologies Chain interface failures in one technology area cause failure in another technology area Failure of a component Miscommunication in human sphere Faults and mistakes in design process	Usual design where all allied technologies act independently and contacts between them are limited to harmonization of products' parameters	Compensation of mutual weaknesses of technologies and amplifying their common useful effects Physical, logical and mathematical optimisation Growing flexibility Multifunctional ability New functions not existing before	
100%	Time to failure	0	Profundity of integration (moving target)	100%
	Negative synergy		Positive synergy	

Figure 1. Positive and negative synergy deployment

Generic foundation of positive synergy is optimisation in its wider interpretation. During the whole history of engineering design one can notice the striving for the optimisation of the result. The simplest way is logical optimisation, always used in design process. In complicated situations, outside the brain's seizure, we have to apply mathematical tools. However, the success of the analytical approach also depends on the level of knowledge about the real physical processes in the product and perfectness of logically developed structure. So it is possible to assert that there are three ways of optimisation – physical, logical and analytical. In reality all these three approaches complement each other, calling forth total synergy of performance. The precondition for granting physical synergy at the different technologies interaction is knowing the gist of integrated processes on such a level that it is fully possible to control these processes. To apprehend the philosophy of synergy integration better we can draw parallels with the social system. As a result of normal education and human development the so-called ordinary people grow up who are able to operate successfully in society and at work on their professional level. However, there is a small group of people whose natural talent has been powered by subsequent education and training giving them outstanding capabilities for fine arts, science, sport, etc.

One of the requirements for moving ahead in synergy-based engineering design methodologies is to use quantitative characteristics of synergy. Quantifying the synergy in artefacts proposes the existence of a synergy evaluation tool and universal scale to measure the products' performance. The scale of measuring may start from 0 for conditional interdisciplinary synergy-free product. So far for the evaluation of the positive synergy it is possible to use only relative parametrical scale based on the benchmarking the similar products on the market. The maximum value on the positive side of this scale means reaching the maximum synergy (100%) where everything has been squeezed out of physical processes. It is impossible to say where the real maximum is, as it means the fixation of the end of any development and further research. The validity of such an approach has the same value as repeating unsuccessful proposals of human limits in sport.

Anyway, it is not possible to ignore negative synergy facts due to their insidious action and a tendency to occur again. Negative synergy is closely related to the reliability characteristics of the system and it reveals itself mostly in the infant mortality period of a new product's life cycle. The classical understanding of a system's reliability is not very suitable for interdisciplinary systems as besides mono-technology failures there are also combined failures or effects of incompatibility on the allied technologies interfaces. A particular component may fail as a direct result of a physical reason, or it may fail as a result of a chain failure of another component of the system. The chain failure can be treated as the negative synergy between allied technologies. In the synergy context reliability can be treated as a process where the synergy of operation of components is gradually reducing (wear, emission, etc) and stops functioning when accumulating negative synergy reaches its extreme value. In order to clear up the roots of negative synergy a 5-year service statistics database for non-safety-critical mechatronic office equipment was completed [4]. Four generations of office machines were under observation. The database consists of up to 3,000 service actions solved in 2000 work hours with the total turnover of 350000 EUR. The analysis of the service database has proved that the negative synergy phenomenon dominates in the infant mortality period of a brand new model The share of interface failures from all service actions (adjusting, cleaning, mono-technology failures and user errors) was 24% which is impossible to neglect. For the brand new product the infant mortality period extends approximately to 1/3 of its lifetime, for a mature product it is between 1/4…1/5. Due to the gradual upgrading of the product negative synergy effects are decreasing and the infant mortality period is nearing to mature one.

It is obvious that to attain the maximum synergy of interdisciplinary systems it is necessary to take into account all substantial interfaces between the components and modules of the system carrying the features of different technologies. The optimistic approach to that opportunity of synergy-based design is founded on the fact that there are a limited number of products available where the synergy of allied technologies is to some extent achieved. But the attaining of this synergy has still been more based on intuition or occasion rather than being the result of a systematic approach. But the matter of the existence of outstanding synergistic products means that there must also exist guidelines for the successful motion in this direction. However, synergy is not only a technical problem, but also involves synergy between product development team members resulting in a successful or failed product. There is still a substantial „white“ area – how to separate the human and technical aspects on negative synergy side.

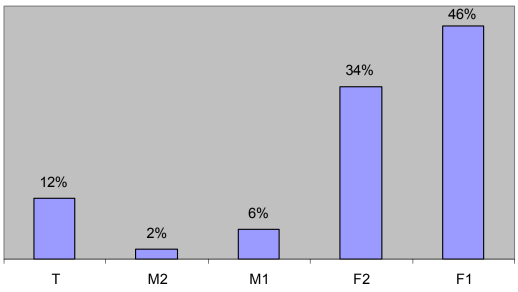
3 Human aspects in engineering

In the previous chapter it became evident that without thorough and detailed research into the human impact on the so-called "bad engineering" it is impossible to evaluate the negative synergy effects in the teamwork and prognosticate the infant mortality risks of brand new products. In the present research all the range of interdisciplinary systems are conditionally divided into three categories: consumer products, equipment control and large factory automation systems. Earlier a similar research was provided for mechatronic consumer products - the office machines [4]. But during the first research it was not possible to separate the human and technical aspects at design as the objective was to study negative synergy effects taking place at equipment use during the infant mortality period. In the present research this approach was enlarged to the field of larger interdisciplinary systems and focussed on human shortcomings in the design and application of the systems developed.

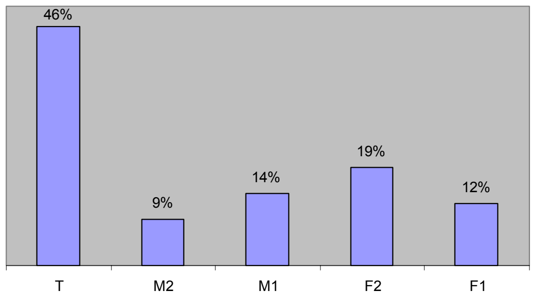
Although the analysis of the shortcomings at the design and launch of control systems is extremely useful for any company active in automation it is at the same time a very sensible domain. Therefore such kinds of research results are very rarely published and so for understandable reasons the companies involved are anonymous. To evaluate the validity of the findings of this research it is necessary to underline that the companies concerned are world-wide known strong contributors in the field of automation.

During the last four years an unique database of human and technical shortcomings was compiled, comprising more than 13,000 equipment and 5 factory automation control systems design and commissioning cases. One of the main problems here is how to differentiate the human and technical side in the negative synergy effects. Wrong decisions of judgement and lack of skill were previously considered as technical problems and were taken as a generic basis of the negative synergy. An analysis of the compiled equipment and factory automation shortcomings database gives a good chance to solve this problem. However, at first it is necessary to specify the terms used in the further analysis. In this database all shortcomings occurring at the design and launch of the interdisciplinary systems were classified into three main categories: human faults, human mistakes and technical problems. Faults are wrong decisions that have no justification. To the faults' category belong communication misunderstandings (F1) between the client and the design team or between members of the design team. To the second category of faults F2 belong all shortcomings connected with negligence. Faults F1 may be treated as a result of negative synergy in teamwork and F2 as negative synergy in person inner communication. Mistakes are usually caused by the lack of competence (M1) or due to unknown matters at the moment of design (M2). So the last part of these mistakes can be recovered in a normal set-up process of the automated systems or in further research and they cannot be treated as causal mistakes. Further the classification of human faults and mistakes is expanded to the next hierarchical levels but the presentation of these results in the present paper would be too capacious. A special category here is formed by technical problems T where a component is working poorly or does not function at all. So, it is obvious that nearly all shortcomings in the design and application process of an interdisciplinary system can be treated as synergy-based ones.

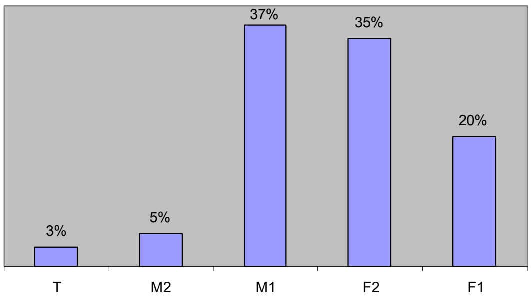
For factory automation it is appropriate to provide shortcomings analysis for two levels - during the virtual factory acceptance test at the systems' supplier and in the process of the commissioning steps where the real automation system is tested. The length of the commissioning stage period ranges from a few weeks to several months, depending on the scope of the system delivered. At equipment control systems the cooperation between the customer and the systems application team is so close and intertwined that only a joint shortcomings analysis is possible. But in this case quite an interesting difference between well-established and comparatively new technologies can be observed. In Fig. 2 the statistical analysis of human shortcomings for equipment control and factory automation systems design and application are presented. In Fig. 2a the statistics of shortcomings for equipment control systems on such a well-established area as electropneumatics/hydraulics systems with programmable logic controllers on the top of hierarchy is shown. In Fig. 2b the same analysis is presented for a comparatively new technology - a servo drives&control is used. A comparatively low share of technical problems can be explained by the maturity of the components used. In Fig. 2c and 2d the statistics of shortcomings for factory automation systems design and application on the factory acceptance test level and commissioning stage are presented.



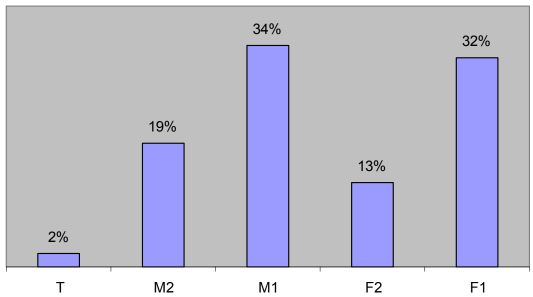
(a)



(b)



(c)



(d)

F1 – faults in human communication
F2 – faults due to negligence
M1 – mistakes caused by lack of competence
M2 – mistakes caused by undeveloped technology
T – technical problems

(a) for well-established technology
(b) comparatively new technology
(c) factory acceptance test
(d) factory commissioning stage

Figure 2. Human shortcomings analysis for equipment control and factory automation systems design and application

In all cases the alarmingly high share of communication faults F1 is seen. At equipment control systems most of the faults are caused by wrong orders as the client and the designer may have a different and sometimes fragmented picture about the control system and its parameters. Only at comparatively new technology communication faults are seemingly compressed by dominating technical problems as most components seems to be still on infant mortality level. At factory automation communication faults have been born on grounds of inadequate initial information, difference of understanding in components functioning, later proposals for user interface, etc. Principle faults are rare. At the commissioning stage the faults share of F1 is still high and it seems that FAT has been superficial and only a part of faults have been successfully eliminated during it. However, the real situation is not so gloomy as at this stage all proposals of final operators and also innovative solutions, worked out during the testing are introduced. The most important problem here is how to improve the synergy in teamwork. Nowadays information technology is offering better on–line communication possibilities for dispersed teams and in some time the share of this type of faults has to decrease. It is absolutely necessary to run a dated database to grant that all changes made in the systems reach all the persons involved.

It is a pity to notice that the share of most easily avoidable negligence faults F2 is comparable with communication shortcomings. It is possible to cut down the most human casual negligence faults by checking the design process continuously using special design tools helping to uncover the most common deficiencies. At the same time the upgrading of the professional level of the personnel and taking unpopular measures to increase the responsibility of the personnel are appropriate. However, there is also another side to the problem – typical overwork of application engineers being the basis of speedy and incorrect decisions.

As it is seen from Fig. 2c and 2d the mistakes M1 dominate in factory automation. The reason seems to be more complicated systems and alternating technologies for automation. It leads to the use of unsuitable components or models, incorrect calculations, wrong integration of interrelated signals, incorrect imagination about tuning parameters, etc. But in the commissioning stage a remarkable part of mistakes M1 is caused by final operators demand to change unsuitable and inconvenient solutions for them. At the development of equipment control systems (see Fig. 2aand 2b) the mistakes share is moderate at new technology and quite small at already established one. The essence of the mistakes here is mainly caused by lack of experience to achieve the needed accuracy or dynamic performance of the system. To avoid mistakes the newcomers to the automation area are recommended to rely more strongly on consulting service in the beginning. Special attention must be paid to the continuous upgrading of the personnel.

To the category of mistakes M2 are allocated all mistakes when it appears that it is possible to establish or to tune the exact parameters of the controlled processes only during the commissioning stage. During the start-up of the systems new unknown matters having effect on production and some mistakes concerning the application of new software may clear up. Sometimes additional units for the smoother functioning of control systems or machines are necessary. The elimination of these mistakes needs some new knowledge about the real processes and automation system functioning. At the same time these problems form a springboard for the further research. The dominating share of the technical problems T at equipment control systems based on new technology is caused by the infant mortality of the brand new components. Sometimes a new apparatus is used that appears later on the market or its parameters are on a lower level than declared. In all other cases the technical problems are mainly caused by the inadequate quality of production of the components used.

All these results are somewhat alarming as misunderstandings and negligence that can be easily avoided in some cases form up to half of all shortcomings. Also, it should be pointed out that the lack of competence of the design team is too dominating. Drawing the conclusion to this chapter it is necessary to underline that the purpose of every automation activity is to offer a suitable, flexible and reliable system meeting the client's needs and expectations and to help them to increase the productivity and efficiency of business. Questioning the engineers and managers in the automation field has shown that these extra costs of removing the shortcomings can attain up to 5% of the system's cost that is in reality quite an impressive sum of money. It is necessary to add that the losses from the production not received are usually much bigger. In conclusion it is necessary to say that the key to reducing the negative synergy effects is to increase the synergy of teamwork at the design and application stages and the team's overall core competence.

4 Generic models for synergy-based design

The main goal of the research in the interdisciplinary systems design is to propose an approach helping to attain the maximum synergy of allied technologies. For the solution of this task a suitable background framework of engineering design methodologies has to be found, enabling to involve synergy metrics and human competence dimensions into design process. The basic idea here is the development of design methodologies of interdisciplinary systems as filtering ones having capability to let through and amplify the engenders of positive synergy and impede the spreading of negative synergy effects caused by the incompatibility of allied technologies. Here it is necessary to point out that the achievement of the maximum synergy is limited by market conditions as the costing of maximum synergy is usually an order higher than market prices allow.

If we take into consideration classical design strategies (sequential, cascade or spiral approaches) they do not include special tools for integrating different technologies. The main shortage noticed in the engineering design methodologies is concentration only on structural and behavioural aspects of designed artefacts synthesized apart from human aspects and market environment. In other words the most of classical engineering design methods are deeply academic. But the effective product development process cannot be built up without taking into account the real situation in the industry and markets. The successful separation of human and technical aspects at the design of interdisciplinary systems opens up new possibilities to move ahead on the way of their synergy-based design opening chance to manage just outlined deficiencies.

The most suitable environment for the design of interdisciplinary systems seems to be the Design Structure Matrix (DSM) technology developed by Steward [5]. Due to the outstanding capabilities to describe the interaction of systems' components the use of the matrix methods has become more and more popular [6]. Eppinger has used this approach for the analysis of the product architecture of large-scale engineering systems and complex interactions between product components, their design process and supporting organization [7]. From the point of view of the synergy-based design of interdisciplinary systems it is possible to involve the systems' engineering approach to make it possible to control the advance in the 3-dimensional design space: not detailed-detailed, abstract-concrete and by steps of the realisation of the artefact. A suitable basis for it seems to be Theory of Design Domains proposed by Andreasen [8]. This theory is based on applying three views of the product – transformations', organs' and parts' domains encompassing of substantial classes of structural definitions and behaviours of artefact [9]. This design concept is realized through horizontal and vertical causality chains. The Theory of Design Domains makes it possible to link the engineering designer's considerations about the interdisciplinary system (delivering effects for the purposeful transformation) via considerations about organs (creating effects) to considerations about the parts being produced and assembled. In this context a suitable tool is the Function-Means tree as a graphical representation of the Vertical Causality Law. Two practical approaches to design process should be distinguished: for functionally new products and for past designs.

It seems that by integrating the technology of Design Structure Matrixes technology and the Theory of Domains it is possible to create a good design environment to involve time and human competence dimensions in the design methodology. In Fig. 3 the essence of the proposed generic model for interdisciplinary products and systems design is proposed. This integration scheme seems to be hybrid and positioned between the areas of descriptive and prescriptive design models. This model makes it possible to take into account both "soft " parameters of design - market conditions and human aspects. In the added domain of market analysis matrix 1 presents the activity-type DSM that allows to take into account the marketing trends and to initiate the synergy-based activities in the firm's product strategy planning so that the developed products should be competitive on the market. Matrix 2 in transformations' domain is a parameter-based DSM that gives algorithm for design process and makes it possible reach the optimal synergy level and performance of the product designed. The optimisation process in this domain is focussed on the transformation of operands like material, energy and data. Matrix 3 in organs' domain represents parametrical activities in the selection of the suitable active elements or organs and their mode of action for interdisciplinary artefacts that create suitable performance effects. Matrix 4 in the part design domain is focussed on allocation or distribution of the organs in the parts, which can be produced and assembled so that all the system's performance tasks are solved and its totality behaviour assured.

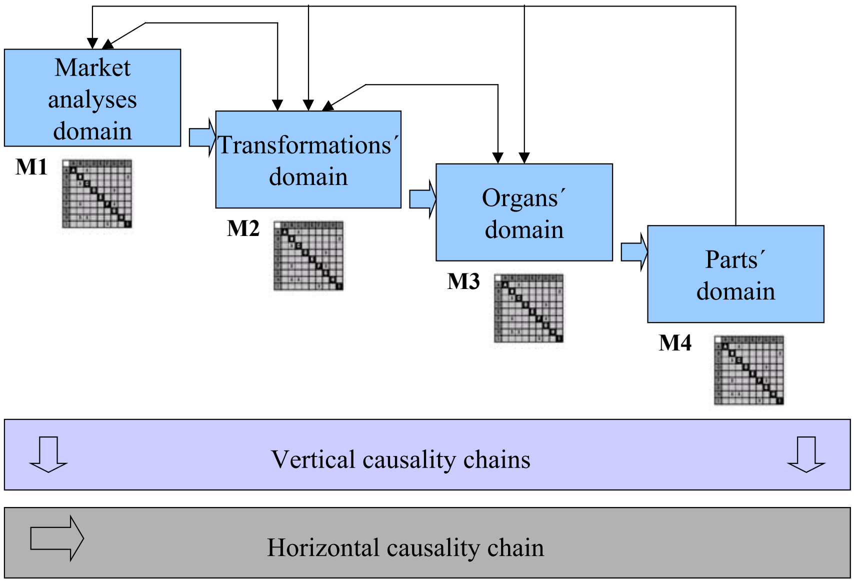


Figure 3. The integrated model for interdisciplinary system design

If to position the synergy-based approach in the engineering design methodologies environment, the main contribution of it is the introduction of an additional synergy dimension of integration. The synergy dimension is introduced to DSM in the form of evaluating its integration power in parameters and processes on 3-step scale. By the transformation of the DSM matrixes it is possible to solve product architecture problems and also clear up the scheduling of processes. Coming closer to the conclusion of this chapter we believe that by using synergy-based approach to engineering design it is possible to develop a new family of adaptive design tools based on the level of competence and expert knowledge of the design team and to synthesize their own roadmap algorithm to move ahead on the way of design process. In this process the statistical probability evaluation of the time for iterations, reworks and learning may be used.

But while using the proposed tool it is necessary to be aware that the composing of the useful and suitable DSM matrix is a complicated process, sometimes time-consuming and this may be a great challenge to design team. The problem is that the DSM is set up on the basis of the expert knowledge and competence of the design team. So the professionalism is simultaneously needed in product architecture, product development process and organisational work and the success in using the design model depends on the existence of these qualifications. The professional team always gets the help in the automatic synthesis of the optimal design algorithm that leads to the better product performance during the shortest design time. The low competence of the design team results in imperfect DSM where some important interactions may be absent or incorrectly evaluated. The badly synthesized algorithm guides the team to the need for restructuring of the matrix. The described circumstances cannot reduce the values of the present approach as no methodology would be effective if used by an incompetent team.

5 Case study for the development of the positioning system

The task of stepping up the synergy level of allied technologies has a goal to reach the market-driven performance with minimal possible expenses on product development and production. It is appropriate to demonstrate the practical realisation of these guidelines on the basis of a real case study which was initiated for raising the accuracy of the existing pneumatic positioning system. The dependence of initial positioning accuracy on the positioning speed was determined experimentally and for the speed interval 0,1…0,4 m/s it is correspondingly ± 0.1…± 0.5 mm. This positioning accuracy (repeatability) contains dispersion of switching time of the controller and pneumatic control valve and also the accuracy of the measuring device. It is obvious that the overrun at the positioning system - from the moment of getting the positioning signal to the full stop can be compensated only by the pre-scheduling of the initial signal.

Task Name	Level		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Market need for higher positioning accuracy	1	1																					1
Market need for cheaper (low-cost) positioning accuracy	1	2																					2
Company´s market share growth strategy	2	3	2	2																			3
Company´s market share keeping strategy	2	4	1	1																			4
Company´s competence sufficient	3	5			1	1																	5
Company´s competence needs upgrading	3	6			2																		6
Upgrading the service level	4	7			1			1			1				1		1						Block1
Service rationalisation	4	8				1	1					1				1		1					8
Positioning the product higher then market level	4	9	2	2	2	1	2	2					2	1					2	1			9
Positioning the product to the market level	4	10	1	1	1	2	1	1					1	2					1	2			10
Improvement of the company´s response ability	4	11			2	1			2								1						11
Retaining the company´s response ability	4	12			1	2				2								1					12
Upgrading the synergy of communication	4	13			2				1				1										13
Retaining the synergy of communication	4	14			1	1				1				1									14
Upgrading the team members inner synergy	4	15			2								1		2	1							15
Retaining the team members inner synergy	4	16			1	1								1	1	2							16
Upgrading the company´s product development ability	4	17	2	2	2	1	1	2	2				1		2		1						17
Retaining the company´s product development ability	4	18	1	1	1	2	2	1	2	1				1	1	1		1					18
Product development needs the additional research	5	19	2		2			2			2	1							2	1			19
Product needs modernisation	5	20	1	1	1	1	1				1	2							1	2			20
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	

Figure 4. Activity-based DSM for market analysis after partitioning

From the point of view of the design this case certainly belongs to the category of past design or modernization and therefore does not need the full content of the design activities compared with the design of a functionally new product. So in the framework of research it is suitable to draw up only two matrixes: the activity-based DSM for the market analysis domain and the parameter-based DSM for the integrated transformations' and organs' domain. When the project reaches the final design at the potential producer it is necessary to compose also the DSM for the parts' domain. As the composing of matrixes needs wider expert knowledge the expert group was enlarged by a special questioning among Estonian and Finnish users and producers of automated equipment. Among other useful knowledge gained it also made it clear that the positioning accuracy ± 0.5 mm satisfies most of the users but on condition that the price raise is moderate the preference was given to the accuracy ± 0.25 mm.

For the market analysis domain the DSM for 20 inputs was compiled, characterizing trends in the present market environment, the product strategy of the company and its personnel competence in product development. It is necessary to point out that the DSM technology is not able to work at contradictory presumptions, for example simultaneously for growing and decreasing market. The present automation market in Nordic countries is by majority of votes evaluated as the decreasing one. The expected outcome from the synergy-based approach of this analysis is to work out the company's external and internal product policy and activities to manage risks in conditions of the decreasing market. All interactions in matrixes were evaluated from the synergy point of view. So far it is suitable to distinguish three categories of synergy integration: 0 – synergy is small or absent at all, 1 – synergy is moderate and 2 – synergy is very strong and decisive for the product's or system's performance. In Fig. 4 the activity-based matrix for market analysis, already allocated to partitioning transformation, is shown. In this transformation process activities are ranged with the goal to move all interactions under the diagonal that leads to the possibility to use the information of previously completed actions in a chain of activities. In real situation this ideal opportunity is usually impossible as sometimes parallel actions are necessary and in some cases the solution of the current task needs some feedback information from the later activity and those bounded tasks are grouped into outlined blocks.

Task Name	Level		1	2	3	4	5	6	7	8	9	
Market need for higher positioning accuracy	1	1										1
Market need for cheaper (low-cost) positioning accuracy	1	2										2
Company´s market share growth strategy	2	3	2	2								3
Company´s market share keeping strategy	2	4	1	1								4
Company´s competence sufficient	3	5			1	1						5
Company´s competence needs upgrading	3	6			2							6
Block1:	4	7	1	1	1	1	2	2				7
Product development needs the additional research	5	8	1		1			1	2			8
Product needs modernisation	5	9	1	1	1	1	1		2			9
			1	2	3	4	5	6	7	8	9	

Figure 5. The timing analysis of the process

Now we have reached the first goal – all activities are scheduled by the best possible way to make it possible to work out the company's survival policy for the period of decline in the industry. All activities are also grouped on the levels, marking the decision-making steps. In the present case on the first level the market analysis is necessary to provide. The two next levels form an invisible block of SWOT analysis. On the fourth level all problems with product development capability and personnel upgrading problems should be solved. And on the last level decisions have to be made about products modernization and research help from universities. This is a simple demonstration case and someone may say that it is a normal way of scheduling activities without any DSM. But normally the research tasks are more complicated and moving out from the brain seizure. It is also necessary to pay attention to the fact that process scheduling is only the first step of the process and the still visible information about the synergy of interactions is so far only partly used. After the collapse of the blocks in the matrix (see Fig. 5) we reach the timing problems of activities.

It is possible to distinguish the critical bindings (numbers in lilac) in the iteration context of the information transfer on the scale: to prognosticate the probabilistic duration of the whole process, giving for all activities optimistic, likely and pessimistic evaluation of duration time, taking into account the learning time (see in more detail in [10]). But it is necessary to remember the main goal of the present research - to reach the optimal synergy between all interactions in all levels of problem-solving. At the same time it is necessary to warn that in strongly intertwined inputs for hardly schedulable process (market analysis is one of these) it is necessary to concentrate only on strong interactions as the dissipating of the use of interactions may lead to the situation that partitioning becomes impossible. But in any case the trustworthy roadmap for the design process is created with possibility to keep a comprehensive overview of the decision-making process. In case of a more complicated situation where the human being is not able to seize the full picture anymore the DSM technology seems to be the only solution.

For the parameter-based DSM, drawn up for the allied domains of transactions and organs the 40 inputs were initially nominated from which after careful selection 28 were selected for the final matrix. The same procedure of evaluation of synergy-based interactions on a 2-1-0 scale was provided. On Fig. 6 the parameter-based DSM after partitioning is presented. The expected outcome from this analysis is a proposal for the structure of a more exact pneumatic positioning device at a moderate price raise. As one can see the five levels of inputs are distinguished. On the first level the invisible block of the initial parameters is seen having no interactions. The second block is a real design matrix where all important design parameters supporting the performance of the product are presented. The last three levels carry the feature of output parameters where the ultimate use of backpressure in the cylinder during braking is estimated. The last two levels belong to the positioning accuracy and price level - to the problems which cannot be solved earlier.

Task Name	Level		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Great mass, 20 kg	1	1																													1
Moderate mass, 8 kg	1	2																													2
Small mass, 1 kg	1	3																													3
Number of intermediate positions: 2	1	4																													4
Number of intermediate positions: 2 or more	1	5																													5
Sliding friction	2	6	2	1					2	2		1	2											Block1							6
Braking with empowering the friction	2	7	1								2	1																			7
Fixation with empowering the friction	2	8							2																						8
High speed of positioning: 0.8 m/s	2	9															2	2													9
Moderate speed of positioning: 0,5 m/s	2	10															2	2													10
Low speed of positioning: 0,3 m/s	2	11															2	1													11
Positioning from high speed	2	12	2	1				1	2		2	2	1																		12
Positioning with stepped down speed	2	13						2	1		1	1	1																		13
Using a correction mechanism after positioning	2	14									1	1	1																		14
Disatance between positions small: 5 mm	2	15	2	1				2	2	2									1	1	2										15
Disatance between positions large: 10 mm	2	16	1					1	1	1									1	1	2										16
Substantial delay of braking signal: 50 ms	2	17												1	1	1															17
Moderate delay of braking signal: 30 ms	2	18												1	1	1															18
Physically minimal delay of braking signal: 15 ms	2	19												2	1	2															19
Tarvel stroke: 1000 mm	2	20	1																												20
Travel stroke: 2000 mm	2	21	2	1																											21
Braking with backpressure	3	22	2	1				1	2		2	2	2	2	2																22
High positioning accuracy	4	23	2	1				2	2	2	2	2	2	2	2	2			1	2	2	2	2	2							23
Moderate positioning accuracy: +/- 0,2 mm	4	24	1					2	2	2	2	2	2	2	1	1			1	1	2	1	2	2							24
Small positioning accuracy: +/- 0,5 mm	4	25						1	2	2	2	2	1	2					1	1	1		1	2							25
Price of the drive favourable : 500 €/m	5	26					1							2	2	2	1	1	2	1	1	1	1		1	2	2				26
Price of the drive moderate : 500 €/m	5	27	1				1		1	1				1	2	2	1	1	1	2	1	1	1		2	2	1				27
Price of the drive high: 750 €/m	5	28	2	1			1		2	2					1	2	1	1	1	1	2	1	1		2	1					28
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	

Figure 6. The parameter based DSM after partitioning

Let us concentrate on the central block where the key of the expected solution is concealed. The synergy level in braking with friction stretches from deep negative synergy at small velocities (perky movement) to the maximum at the physically impossible instant braking with enormous braking force. At the same time friction is absolutely necessary at fixing the achieved position as this way is much cheaper and more accurate than attained by the use of expensive servo systems.

The increasing friction in combination with using the backpressure in the cylinder in the present prototype seems to be a good idea but does not give the expected result in accuracy. The best solution to the problem is the situation where all participating elements are integrated on the basis of the maximum synergy of their mutual interaction. It means that the system must be built on the basis of roller sideways and with the exact optimal speed control servo with a separate braking system that all together is so expensive that it is impossible to sell them on the market. The constructive idea of the present research is to compress the system to the dimensions of a correction device without losing the synergy of actionof the whole system. It results in the correction mechanism with friction-free elastic pneumatic drive controlled by the pressure, proportional to the positioning error. The model of this system was experimentally tested and the results are encouraging. The accuracy of positioning of the model is ± 0.0045 mm that is competitive with the accuracy of the measuring system and it is far more accurate than market expectations. The estimated price of the system is 40…50% higher that of the prototype. Behind it all is physical-logical optimisation with the aim to increase the synergy of the system. So the situation is reached when the cooperation capabilities of the system elements are used in a synergy-based manner on the optimal level taking into account price limits on the market and that is the essence of the synergy-based design.

5 Conclusion

While evaluating the findings of the present research, the most important result is the arrival at the truth that the synergy-based approach to the interdisciplinary systems design is a possible way to create a complete picture of all the realities of the design process. On the basis of an unique research on human mistakes and faults at new equipment control and factory automation systems an analysis for the separation of technical and human factors is provided. It is shown that the integration of the Design Structure Matrixes technology with the Theory of Design Domains is a suitable basis for synergy-based design methodologies of the interdisciplinary systems. A new family of product development tools for the design of interdisciplinary products and systems is being developed where synthesis of the decision-making algorithm is based on the competence and expert knowledge of the design team.

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