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THE RELATION BETWEEN PROJECT RISKS AND ROBUSTNESS OF DESIGN – A CRUCIAL FACTOR OF SUCCESS IN PLANT ENGINEERING

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1. Introduction

Designers are facing various challenges in product development: a rising product complexity especially caused by electronics and software components, market demands such as shorter development time and cost pressure as well as communication within heterogeneous company structures. These determining factors lead to an increasing number of design errors in practice.

The number of product call-backs points to this problem. In the automotive industry the number of call-backs because of errors and component defects on the German market increased from 55 cases in 1998 to 123 cases in 2005 [Kraftfahrtbundesamt 2005]. Mechanical defects (84 out of 123 cases) are predominant. In Europe 11 products per week need to be called back because of errors or safety problems [PriceWaterhouseCoopers 2005].

In plant engineering – the design, manufacturing and installation of production lines such as assembly lines for automotives or power plants – customer requirements are rising as well: increasing plant output, higher efficiency and cost pressure due to global sourcing lead to growing project complexity and risks. A tendency towards lump-sum turnkey projects can be observed: the contract is closed on a fixed price base and includes as well the engineering and construction components of a plant. The advantages for the client are price certainty, efficiency in the preparation and quicker deliverability. For the contractor however this contract has a higher risk profile: risks arise from design and engineering miscalculations, unclear product specifications and the performance risk of numerous subcontractors.

A crucial factor to evaluate the potential project risk is the ability to analyse previous project cases and to benefit from these experiences. The information however must be easily accessible and linked to the designer's context in order to be useful [Bennett and Sloan 2003]. The quality of the documentation and the time allowed to review design steps is essential [Suther 1998]. In order to record and analyse previous projects in a systematic way and to bring the gained knowledge in the designer's situational context a computer-based error tracking system has been developed and introduced in the industrial context of a mechanical engineering company [Möhringer 2007].

The analyse of design errors shows an interesting phenomenon: the same design error happened in different projects showed dissimilar consequences. In some cases the error had no effect on the design robustness, in other cases the error was decisive for the design robustness and even the success of the entire project. Therefore the relation between the project specifications and the design robustness needs a more detailed investigation.

2. Objectives

Risk assessment is an important task in plant engineering in order to decide about a potential project. With rising project volume, complexity and enlarged responsibility this assessment becomes absolutely essential because the project risks can endanger the company's livelihood.
It is the objective of this contribution to analyse the recorded errors in relation with the project context. As a first step the project risks in plant engineering are specified. Then the impact on the robustness of design will be investigated. Finally an approach is presented how to anticipate project risks in correlation with the design robustness.

3. Project risks in plant engineering

Project risks cover a wide area, the technological area is only a small part.

risk area	**risk specification**
technology	degree of novelty requirements to operate degree of efficiency availabilty of service
market	country-specific features market potential
customer	market position reference costumer ability to visit with others reputation price or quality oriented
climate	temperature humidity sea air
currency	stability rate of exchange
financement	assured financing down payments public fonds
logistics	route of transport weather-dependent transport time clearing conditions
project management	technical competence project ressources
operation conditions	operator skills infrastructure power supply
contract conditions	general terms and conditions contract penalty hand-over conditions
unforeseen events	shortage in ressources company is sold

Figure 1. Potential risks in plant engineering

The main aspect in technology is the degree of novelty which means the percentage of newly-developed, unproven components or machine aggregates. This degree of novelty need to be reflected in relation with the other risk areas, especially with the type of customer and the operation and contract conditions. The worst case need to be anticipated: what happens if the new components fail and don't fulfil the performance foreseen in the contract? The action alternatives (e.g. amendment,

replacement) need to come along with the contract conditions. Rigorous penalties and claims for indemnification may leave only limited reaction time. In this case a proven technology seems to be the right choice.
Decisive for the success of a technology is the customer's ability and attitude to operate the plant. In semi-automatic processes where the process demands the intervention of an operator – quality control, handling of difficult goods etc. – the total plant performance depends on the operator's qualification and working attitude. The contractor need to contribute his part such as training, production monitoring or teleservice. But the customer remains the disciplinarian of the operators and provides the production management. The degree of professionalism of a so far unknown customer is a serious risk.
The risk areas (see figure 1) have to be evaluated in interdependency in order to judge the total risk.

4. The impact on robustness of design

The risk areas have furthermore an impact on the robustness of design. Robustness is the ability of a system to perform as expected over time and to maintain its functionality across a wide range of operational conditions – insensitive to changes in manufacturing, operational or environmental factors. In the life sciences, robustness has been an implicit theme for more than a century. Different conditions arise, for example, from environmental variation, input perturbation, sloppiness of system components, and subversion [Kozola 2008], [Hammerstein et al. 2006].
In our case of plant engineering the robustness of design is determined by the design specification in different design areas (see figure 2).

design area	**design specification**
plant performance	plant output (peak)
	plant output (average)
	resource recovery
	energy consumption
plant adaptability	set-up times
	modified products
	range of products
	fluctuating capacity
	availability
stability/durability	service life
	maintenance costs
	down time
easy to operate	operator qualification
	fault-tolerant
	easy to configure
easy to maintain	standard components
	quality of documentation
	service interval
resistivity	temperature
	dust
	humidity

Figure 2. Design specification

The design is considered as robust if it fulfils not only the core requirements of a plant such as performance but also design criteria which are relevant mainly after the guarantee period has run out. This is for instance the long-term durability or the maintainability.
The customer's buyer attitude (price or quality orientation – risk area customer) plays an important role to determine these design specifications. They have of course a wide influence on the project's sales price.

The data base to evaluate the risk of new projects are the experiences made in previous projects. Experiences and errors are recorded by the error tracking process. The error tracking process is described as a sequence of process steps which typically need to be passed through when handling errors. Each process step has an information input and produces an information output. The process step is furthermore supported by appropriate methods and software tools. Specification techniques help to describe the results of each process step [Möhringer 2007].
The core element of the error tracking system is a software which has been developed within the company based on MS Access. It combines database functions with work flow elements. Every error can be recorded into the database supported by pre-defined entry sheets. Additional information such as photos and sketches can be loaded and linked. The whole process to treat errors including the knowledge transfer is supported.
Figure 3 shows the error evaluation module which is essential to access the project experiences. The error reason, error origin and the error costs are described in the system, the context and the search keys can be refined. A wide search function allows to scan the data by search keys (search items, object- and function-oriented), projects, components, persons, customers etc. The information and guidelines concerning a specific area can be scanned as well. The designer can check the history of a solution in order to anticipate eventual knock-on effects, relations to other components, practical experience and life time.

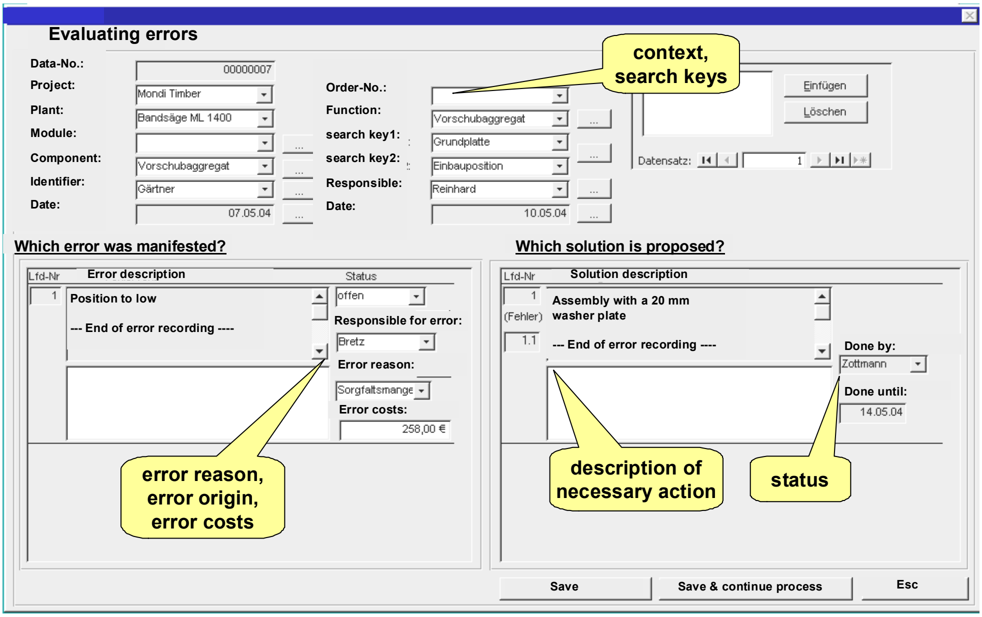

Figure 3. Error evaluating module

5. An approach to anticipate project risks and the impact on design robustness

The information from previous projects include their individual risk situation. A design which is considered as robust in a specific project don't has to be robust in a new project context with a different customer even if the technical specification is identically.
Therefore the decision about design robustness has to be correlated with the potential risk of the new project. In order to evaluate the correlation a matrix is build considering the risk specification parameter and the design specification parameter (see figure 4).

Correlation matrix

valuation criteria:
0 = no influence
1 = weak influence
2 = medium influence
3 = strong influence

risk area		risk specification	plant performance				plant adaptability					stability/durability			easy to operate			easy to maintain			resistivity		
		design specification	1a plant output (peak)	1b plant output (average)	1c resource recovery	1d energy consumption	2a set-up times	2b modified products	2c range of products	2d fluctuating capacity	2e availability	3a service life	3b maintenance costs	3c down time	4a operator qualification	4b fault-tolerant	4c easy to configure	5a standard components	5b quality of documentation	5c service interval	6a temperature	6b dust	6c humidity
technology	1a	degree of novelty														3							
	1b	requirements to operate													3								
	1c	degree of efficiency									3												
	1d	availability of service																					
market	2a	country-specific feature																					
	2b	market potential																					
customer	3a	market position																					
	3b	reference customer	3																				
	3c	ability to visit with others																					
	3d	reputation																					
	3e	price or quality oriented									3												
climate	4a	temperature																			3		
	4b	humidity																					3
	4c	sea air																					
currency	5a	stability																					
	5b	rate of exchange																					
financement	6a	assured financing																					
	6b	down payments																					
	6c	public fonds																					
logistics	7a	route of transport																					
	7b	weather-dependent																					
	7c	transport time																					
	7d	clearing conditions																					
project management	8a	technical competence																					
	8b	project ressources																					
operation conditions	9a	operator skills													3	3							
	9b	infrastructure															3						
	9c	power supply																					
contract conditions	10a	general terms and conditions																					
	10b	contract penalty																					
	10c	hand-over conditions																					
unforeseen events	11a	shortage in ressources																					
	11b	company is sold																					

Figure 4. Correlation matrix between project risks and design robustness

The strength of correlation is evaluated with criteria from 0 (no correlation influence) to 3 (strong correlation influence). With the help of the matrix the design robustness of a potential project can be configured according to a specific risk profile. This allows a very accurate configuration avoiding over-engineering and assuring design robustness in critical and risky areas.

In the example in figure 4 the risk specification "reference customer", "operator skills" and "infrastructure" is considered to be critical. This project shall be used in the future as a reference project to improve the company's image and to demonstrate the technology to potential customers in the area. A reference customer has to fulfil the following qualifications: good reputation in the market, technology leader, open for reference visits of other companies, high level of maintenance and operation availability, clean and representative infrastructure etc. For the benefit of a reference customer the supplier is prepared to provide special effort into the project: attractive price conditions, latest technologies or optional equipment. However there can be a higher risk involved: the customer is usually demanding and needs particular attention, the after-sales service is more costly to assure the plant availability, errors or weakness during project management can create negative image due to the awareness of the customer. In the matrix a strong correlation is identified with the design specification "plant output (peak)". For a reference project the peak performance is especially important because the potential customer visits the plant only for a relatively short moment. He judges the plant performance on the basis what he has seen. Therefore the design robustness must consider the peak performance with priority.

"Operator skills" and "infrastructure" show a strong correlation with "operator qualification", "fault-tolerant" and "easy to configure". The risk area of operation conditions is considered to be critical. This is the case if the qualification level of the operators is generally low (country-specific), the company's attitude towards labour skills or the availability of qualified operators in a specific area. As a consequence the plant must be designed for easy operation, process configuration and maintenance. The level of service (tele-operation, tele-service) should be sophisticated in order to support the plant independently from distances and time zones.

The example shows that the awareness of project-specific risks has an important influence on the design robustness and finally on the success of a new project.

6. Application

The presented approach to anticipate project risks and the impact on design robustness can be applied in daily project work as follows:

1. Determine project risks

First step is to determine the key project risks of a new or potential project. With the help of a check list (see figure 1) and the classification into risk areas this can be done systematically and efficiently.

2. Analyse the impact on design robustness

Second step consists in analysing the correlation between the key project risks and the design specification determining the overall design robustness (see figure 4). According to the strength of each correlation a ranking of design specification can be built.

3. Determine critical design areas

This allows to identify critical design areas which need to be focussed on (see figure 5). These areas should be treated with special attention because they have the strongest influence on the design robustness.

In the mentioned example where operator skills are considered to be weak the user-friendliness of the plant should be a design focus. The design will be robust if the following design features are fulfilled: self-explaining operator panels and software layout, control of plausibility when settings or production data are modified, self-diagnostic routines (sensor input signals, maintenance circles, calibration processes), comprehensive fault description and displaying in case of unforeseen production stops etc.

4. Evaluating errors of critical design areas

The error tracking system helps to transfer knowledge from former projects into potential critical design situations. The search function allows to scan the data by search keys (search items, object- and function-oriented), projects, design specification etc. Experiences of weakness or under-estimation in design robustness can be analysed and the designer can evaluate whether a similar problem could occur in his new design task. The error tracking system will show him as well a selection of possible design solutions.

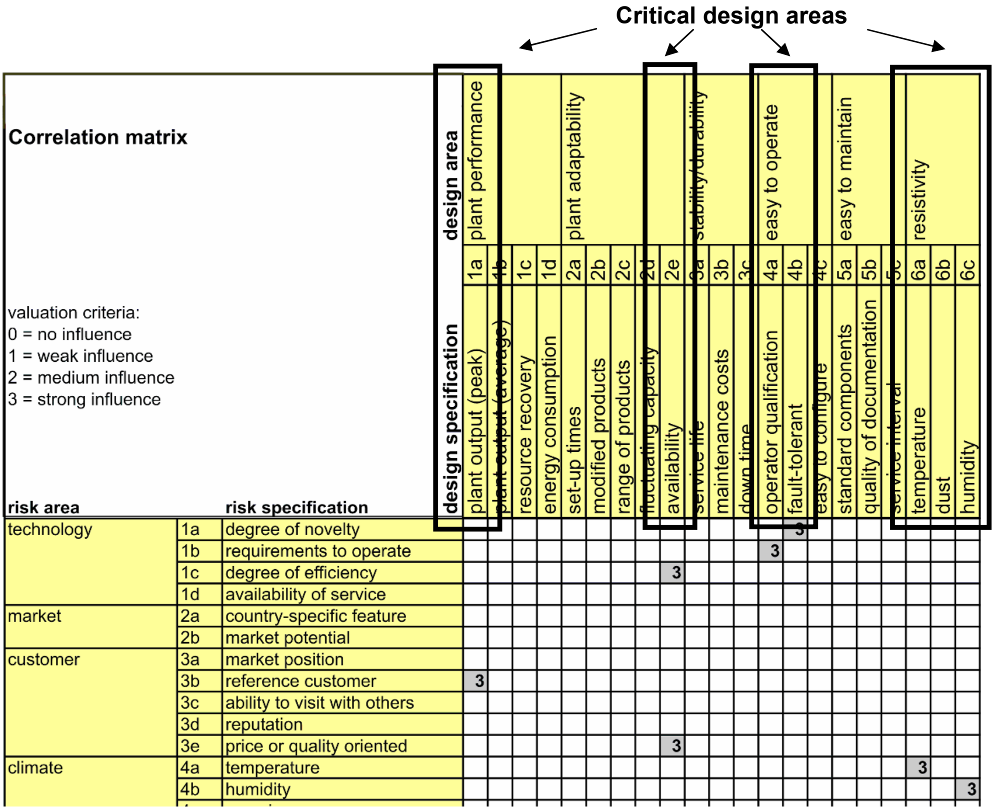

Figure 5. Determining critical design areas

7. Conclusion

In competitive markets with global sourcing and cost pressure the acquisition phase in plant engineering is essential. On one hand it is the aim of the contractor to quote a project with the best price possible in order to compete. On the other hand a considerable risk is involved with every quotation. Especially in the case of lump-sum turnkey projects all costs need to be anticipated and included. The margin in plant engineering does not allow to include reserves for eventual calculation errors.

The experience gained in previous projects is a great help to evaluate the risk of a potential project. The project managers know about country-specific particularities, unforeseen complications etc. In the discussed company example an error tracking system has been implemented to record project experience systematically and to allow the transfer of knowledge into new project situations. It has been used so far in the conceptual and detail design phase.

A new approach is presented using the experience of error situations to evaluate the risk in the acquisition phase. The risk areas and the risk specification of a potential project are identified and individually evaluated. In addition to this the design robustness of the project is configured. In order to achieve a configuration as accurate as possible a matrix correlating the project risk and the project design is established. The matrix helps to identify the critical design areas and their specifications which are highly influenced by the project risks. These design areas can be optimized to minimize the potential risk. On the other hand non-critical areas can be eventually "downgraded" to save costs and to benefit in price competitiveness.

The next step could be to integrate the risk specification into the error tracking system. That means an error should be recorded together with the individual project risk background. This would allow to valuate errors by risk criteria. In case of a new project risk assessment the project experiences could be selected according to the specific risk grade relevant for the current case.
The value of the information would be more specific and adapted leading to higher valuation accuracy and time saving.

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