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MAPPING RISKS ON VARIOUS PRODUCT DEVELOPMENT PROCESS TYPES

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Summary

The goal of this research is to enhance the understanding of various categories of risks in product development (PD) and to carry out a comparative study on how risks occur in different phases of PD processes. Based on an extensive literature overview and the analysis of several risk identification methods, a Risk Breakdown Structure was created for product development. Mapping of identified risks, as the main contribution of the presented research, provides information about the existence of certain risk categories and subcategories in different phases of the product development process. The obtained information facilitates more successful risk identification in PD. The mapping was created in order to enable a comparison between certain PD process types by using the criterion of suitability for managing and coping with specific risk categories. To validate the proposed mapping, a questionnaire was sent to R&D organisations.

Keywords: *product development process, risk mapping, Risk Breakdown Structure*

1. Introduction

Complexity of products and product development processes, but also a multi-objective project perspective, can significantly influence the progress of a product development project [13]. In order to accomplish a successful product development project, companies should not only focus on the final outcome – a new product – but also on the mitigation of various categories of the development process risks [34].

The main interest of the research presented in this paper is to enhance the understanding of various categories of risks in product development (PD) and to carry out a comparative study on how a risk occurs in different phases of PD processes. The objective of the presented research is to propose an improvement in the identification and perception of risks in product development in terms of mapping the recognized risk categories in the phases of the sequential and spiral PD processes. Risk maps of PD processes should provide an insight into the frequency and importance of certain risk categories within and across PD phases and should establish the basis for a comparison between different PD process types from the perspective of risk management. The proposed mapping was validated based on a qualitative and a descriptive approach using a questionnaire as a survey method to gather information

from industry representatives. The presented research includes a comprehensive literature overview in the area of risk identification and management in product development.

A description of the research background and the related work is given in the next chapter which includes a discussion on relationships between risk models, risk management and product development process types. Results of the research synthesis are presented in section three, including the creation of the Risk Breakdown Structure (RBS) for the general product development process and the mapping of identified risk categories of different product development process types. Examination of risk perception and identification within companies in order to validate the presented results is followed by conclusions and proposals for the future work.

2. Research background and related work

2.1 Understanding risk in the product development context

Although many definitions of risk in product development can be found in literature, the presented research adopts the one provided by Smith and Merrit [31] "the risk is the possibility that an undesired outcome disrupts your project". Argumentation for such a choice, among others, lies in a strict perception of a risk in a negative and adverse way, as a threat, despite the fact that certain standards [2, 20, 29] and researchers [5] comprehend risk as a term that could represent an opportunity.

This definition implies two components of risk, probability (also found in literature as likelihood or frequency) and impact (or severity or consequence). To describe factors that influence these risk components in the product development process, a risk model should be used. Risk models provide an insight into the nature of risk and elicit common understanding of risks in PD. Even though there are a few risk models (Ishikawa, Simple) applicable to the product development process, the Standard Risk Model was recognized as the most appropriate since all other models could be derived from it [31]. On the basis of these models, a risk management approach can be established.

2.2 Risk management

In the studied literature, risk management approaches include identification, analysis, evaluation, treatment and monitoring of risks [3, 20 (Figure 1), 26, 29, 31]. Some authors describe risk management approaches with various levels of details and also some additional activities, such as planning in advance, prioritization, etc. [10, 30]

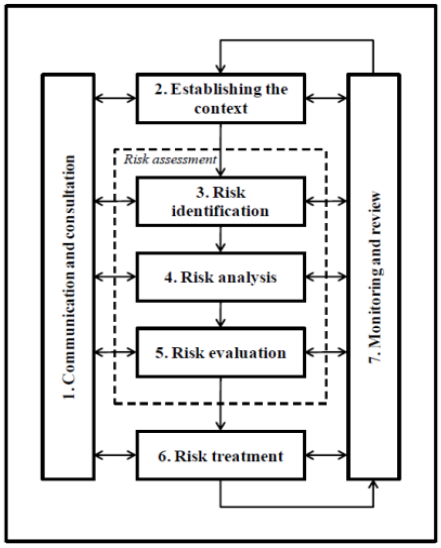

Fig. 1 Risk management process [20]

Risk identification is a phase of recognizing and identifying risks for which heuristic, analogical and analytical methods can be used [15, 20]. During the risk analysis, probability and impact of risks should be estimated so that in the next step they could be properly treated and mitigated according to particular risk strategies [14]. Finally, risks need to be continually and repeatedly reviewed and monitored to maintain the desired course of the project.

In the presented research, particular emphasis is placed on risk identification. According to some authors [7, 12, 31], risk identification, as the initial phase of risk management, is considered probably as the most important step because risks cannot be managed if they are not identified. In addition, Kloss-Grote and Moss [21] consider this phase as the most challenging phase of risk management process. All other risk management phases of product development rely on the identification phase implying the necessity for a clear and comprehensive overview of risks.

2.3 Product development processes – a risk management perspective

Risk management, when addressed in the product development process, should help to cope with a dynamic technological and market environment and should have a major role in the development project [31]. It starts at the very beginning of the product development (PD) process and lasts throughout the whole process. Due to possible cost overruns, schedule delays and insufficient product quality, which are often encountered in everyday PD practice, there is a significant need for a proactive and cross-functional perspective of risk management.

In literature, various types of product development models can be found. The most commonly used models are sequential PD models whose main representative would be Stage-gate, also known as a waterfall model. Stage–gate assumes that the linear proceeding and continuation of the process to the next stage is determined by a positive evaluation at the preceding gate (kill-go decision). On each milestone, risks are assessed and monitored, but further progress is allowed only when it is possible to answer crucial project (technical, market, etc.) questions. Therefore, the model strongly depends on advance planning and proceeds well when customer requirements are stable; otherwise, expensive inter-phase iterations are required.

In a spiral model, feedback loops and overlaps of different PD phases emphasize the iterative nature of product development. This completely different perspective was initially proposed by Evans [9] (Figure 2), in which the stage and the activity modelling are combined in order to describe the iterativeness of the ship design process [37]. On the same basis, Boehm [4] presented the spiral product development as a risk-driven approach because of its flexibility even in later phases.

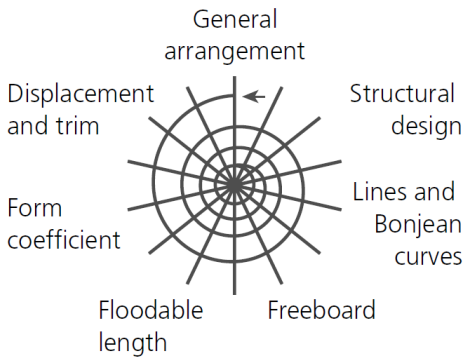

Fig. 2 Evans' model of ship design process [9, 37]

Comparison of the sequential and spiral PD process types was seen in [34] where a way of characterizing PD processes was suggested. Main characteristics of PD process were expressed with review and iteration parameters. With these metrics, the spiral development process can be described as a cross-iteration process with flexible reviews. Conversely, the sequential development process allows narrow iterations and prescribes rigid reviews. Afterwards, on this basis, a PD process design method was proposed. The method should help companies in planning and selecting PD processes with respect to their risk profile [35].

Oehmen and Seering [24, 25] discuss uncertainty types in product development and in order to further describe risk characteristics, mapping should be a next step forward. Understanding positions of risks in a PD process could also facilitate assigning risks to iteration cycles and reviews [35]. However, prior to that, it is necessary to recognize and identify risks, which have to be mapped on the above-mentioned two process types, using some of the risk identification techniques.

2.4 Risk identification and Risk Breakdown Structure

As stated in ISO 31000 [20], every "organization should identify sources of risk, areas of impacts, events (including changes in circumstances) and their causes and their potential consequences" at the beginning of the risk management process. Risk identification is strongly iterative process since it is hard to identify all risks at once. Therefore, sessions should be performed on regular basis during the project in order to identify risks to the maximum possible extent. Throughout the development project, new risks may appear or new information is gained and previously unrecognized risks now become knowable [23].

Nowadays, numerous methods can be found for risk identification in PD [19, 25, 29, 31], such as brainstorming, Delphi, Nominal Group techniques, checklists, FMEA, FTA, questionnaires and interviews, diagramming approaches, etc. Hillson [17] claims that the "best method" cannot be found, but their combination can be used for a certain project.

Although there are plenty of identification methods, there is no proper procedure for choosing them with respect to various types of development projects. In their work, Ferreira et al. [15] tackle the selection of risk identification methods. They recommended criteria for choosing an adequate identification approach, such as product design and project management maturity levels, product innovation degree, project team knowledge, and time. They have classified methods by their characteristics and divided them into three, already mentioned, categories: analogical, heuristic, and analytical.

The risk identification phase often results in a long and unstructured risk list that cannot help the project manager to deal with risk management [18]. For that reason, risk structure could be helpful for describing and presenting risk decomposition under consideration in a standardized and consistent way. Risk Breakdown Structure (RBS) method can be used for structuring risks in product development.

RBS is defined as "A source-oriented grouping of project risks that organizes and defines the total risk exposure of the project. Each descending level represents an increasingly detailed definition of sources of risk to the project." [18]. In other words, it is a hierarchical structure of possible risk sources, or to be more practical, a checklist [27]. Although the definition indicates a source-oriented categorization of risks, in some RBSs decomposition is made according to product development phases or stakeholders, which causes inconsistencies within structures.

Using the RBS, project risks are divided into categories which are further subdivided in order to form a hierarchical structure. According to the need for a certain level of detail, categories can be further subdivided or they can be aggregated to achieve a more general form.

The main benefit of the RBS, due to its comprehensiveness and universality, aids the risk identification, encouraging participants to identify and elicit risks under all categories. It can be used by various stakeholders and extended according to various perspectives that should be an integral part of every risk management process. RBS, as a prompt list or a checklist, can enhance and facilitate formal brainstorming sessions or interviews by revealing potential gaps in risk identification. A hierarchical arrangement of risk categories can facilitate the recognition of double counting and interdependencies of different risks. Furthermore, it can be used for the assessment and comparison of different projects. Also, lessons learned should help to perceive recurring risks and, accordingly, to act proactively towards risk in the projects to come [18].

In the quoted literature, there are several examples that resemble hierarchical risk structures [1, 6, 8, 16, 28, 32, 33]. These risk structures are mostly focused on the civil engineering (mostly construction engineering) domain, and for that reason, in this paper, a new RBS is made for a general product development risk. The idea behind the created RBS is to develop a RBS for the product development process and to avoid inconsistencies and gaps which can be easily recognized in some attempts. This RBS should provide a unique view of the risk sources in PD, decomposing a product development risk into layers with more details in each layer by using the top-down analysis.

3. Risk Breakdown Structure for product development

Hillson [18] proposed the methodology of Risk Breakdown Structure (RBS) in order to understand risks. A basis for tailoring a RBS for PD was established according to Hillson after a comprehensive literature overview and an analysis of risk structure examples. As it is shown in Figure 3, product development risks may be divided into two main categories regarding the source of risk: internal (identified as risk sources within company) and external (risks that originate from the PD environment). This first-level classification of PD risks is the most natural and it has already been encountered in literature several times. Internal risks usually fall under the project management team control while external risks cannot be controlled.

These two categories are further divided into subcategories. The criterion for classification was the type of risk source that determined its position within a particular subcategory. Four levels were estimated as levels with a satisfactory granularity, but also high enough to elude various risk source problems. Thus, the overlapping of subcategories at lower levels, as a result of different sources causing the same risk event, can be avoided without sacrificing the consistency of our structure. As can be seen in Figure 3, some risk categories are decomposed to the third level due to the fact that these categories are detailed enough for the purpose of this research (e.g. Social risk).

Internal risks categories include Management, Financial (internal), Technical and Organizational risks. Management risks represent a group of risks which are dealt with by the upper management and which include the corporate strategy and contractual risks. Financial risks are related to the financial feasibility of a project, and organizational risks are connected to the organization of processes and personnel. Technical risks are risks connected with the technical feasibility and technical quality of the product.

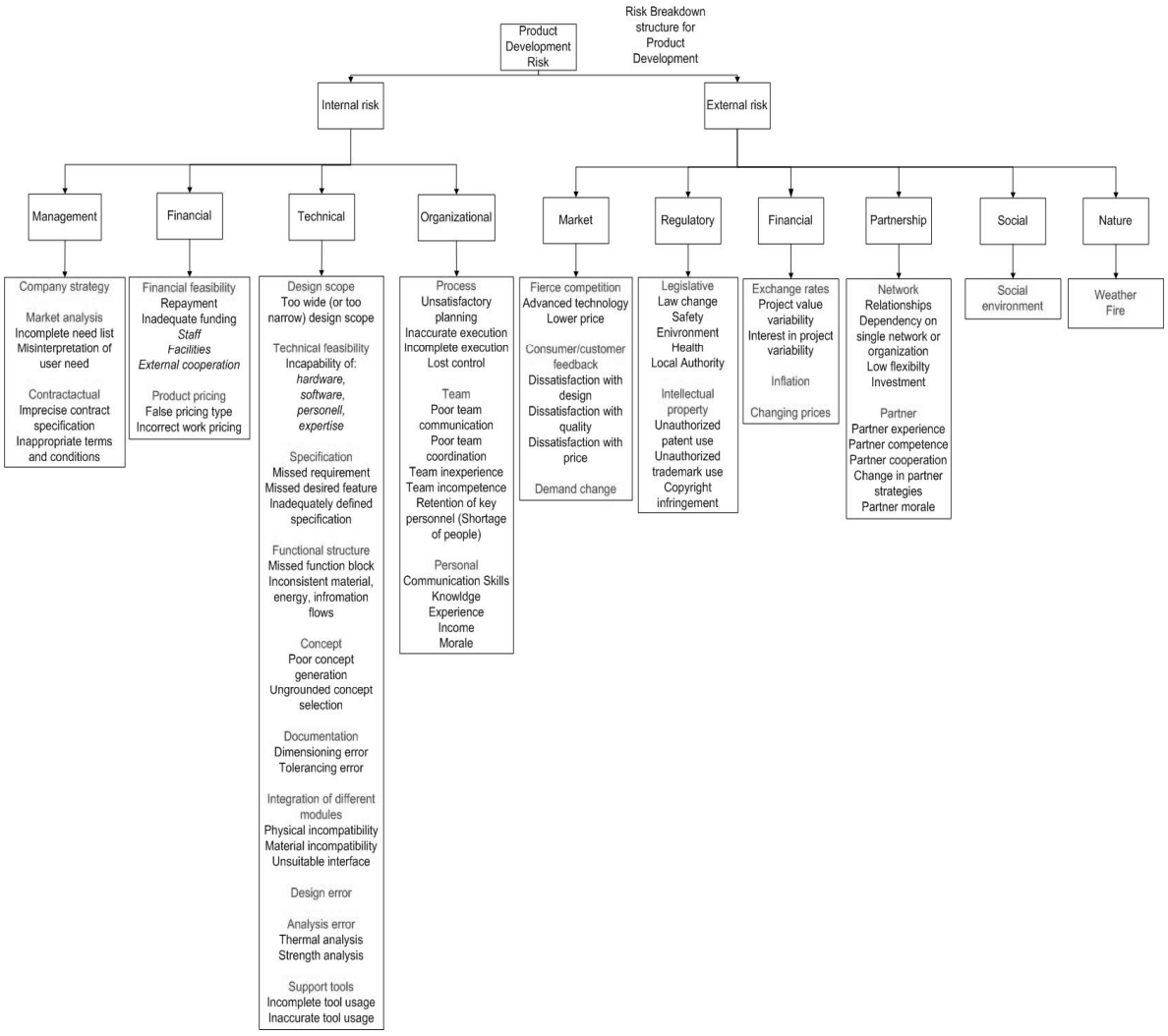

Fig. 3 RBS for product development

External risks are divided into five categories: Market, Regulatory, Financial (external), Partnership, Social, and Nature risks. Financial (external), Social, Nature, and Regulatory risks are categories of risks representing the surrounding environment, which cannot be controlled because they are exposed to various exogenous factors. Partnership risks arise from relationships with partners and from partner networks. Market risks are, in many projects, the most important category encompassing all the risks associated with customers and their demands.

Risk events can be attached only once to a certain risk subcategory which needs to be at the lowest level of RBS. New risk events, which will be added to the existing risk event repository as a consequence of iterativeness of risk identification process, also have to be linked with the bottom level of RBS with a special emphasis on the consistency of the structure. During the project, irrelevant and negligible branches (for that specific project) can be aggregated in order to provide a clear and adapted RBS.

Subcategories, at lower levels, are not conclusive since no RBS is complete as a consequence of a wide spectrum of risks in different fields of product development and therefore there is a need for a tailor-made RBS for different project types in PD. Depending on the user preferences, the structure can be broadened or adapted while considering various stakeholders or project objective aspects (“iron triangle”). Nevertheless, this RBS can be used

as a starting point, but it needs to be updated and extended in order to build an exhaustive database of possible risk subcategories and risk events.

Although the further development of the present RBS is mandatory, it already encompasses the main areas of risks in the product development process. As the next step of the research, the categories and subcategories which were identified in the RBS were assigned to various product development phases of the sequential and spiral product development process types. The mapping was created in order to enable a comparison between certain PD types by the criterion of suitability to manage and cope with specific risk categories. To validate the mapping, a survey on risk occurrences was conducted in development companies among participants in product development.

3.1 Mapping risks on product development processes types

The sequential process model presented in Figure 4 has been taken from [27] as the model includes similar activities to those in a sequential product development process. Figure 5 shows a generalized version of spiral product development process developed by [34] which was used for the second mapping process. These mapping processes are based on a comprehensive literature overview and, afterwards, they will be confirmed by survey results. Figures 4 and 5 also show how different categories of risks, identified and classified by the RBS, are mapped regarding their appearance in the sequential and spiral PD processes. Technical risks are scattered in both pictures and it seems that they may be encountered in the majority of PD process phases regardless of the process type. Technical risks categories and subcategories, which are mapped on these two models, are part of the third and the fourth level of the RBS. Strict and rigid reviews in the sequential processes cause the early freezing of specifications, while in the spiral process they remain flexible, resulting in the reduced control of technical risks [34]. During all phases, technical risks are constituents of product development and they may appear especially at operative levels of the process decomposition where designers try to decrease their impact on the final quality of the product using well-known design methods and heuristics.

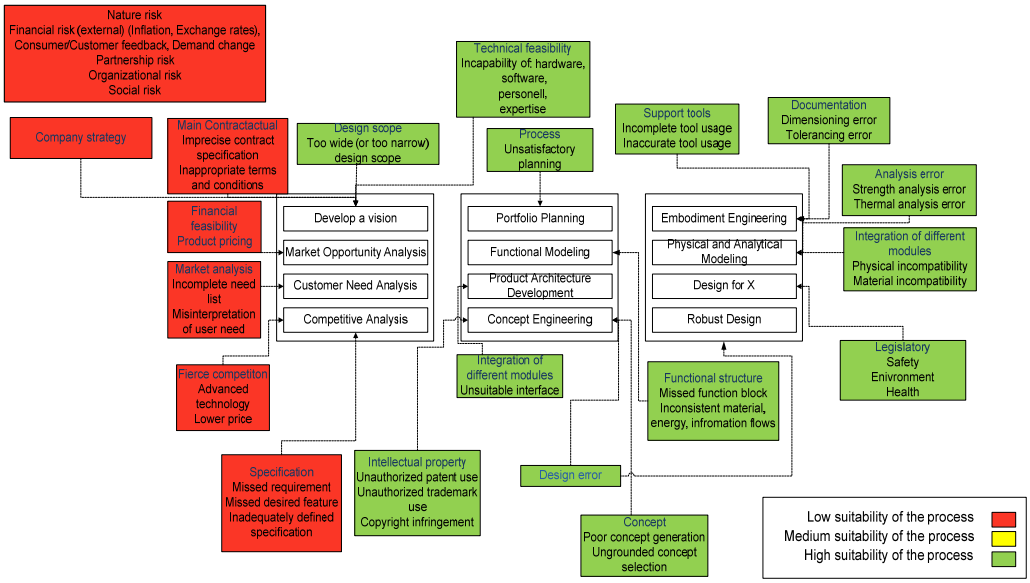

Fig. 4 Mapping on the sequential product development process

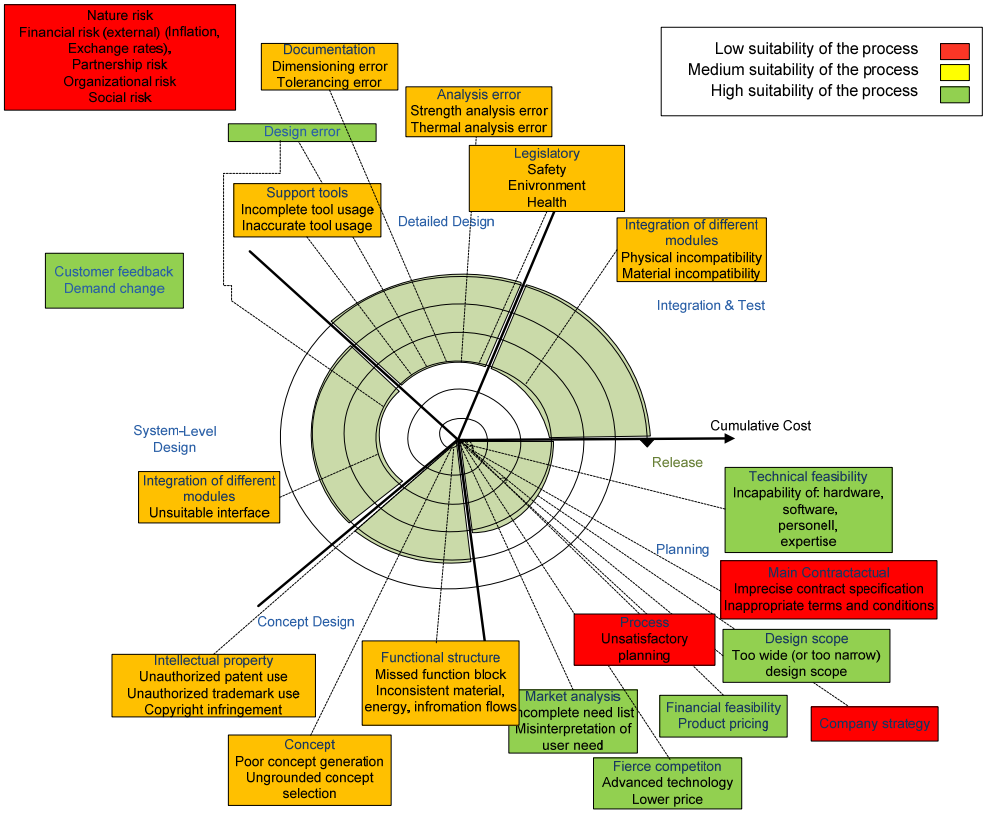

Fig. 5 Mapping on the spiral product development process

A group of external risks, which may influence PD processes regardless of their type, is illustrated in the upper left corner of Figures 4 and 5. This group encompasses risks that cannot be directly mapped on a certain phase because these risks are omnipresent and they cannot be linked to any specific phase. Furthermore, some of these subcategories (which belong to the category External) cannot be controlled by the project team. The group is consisted of Nature risk, External Financial risk, Partnership risk, and Social and Organizational risk. These risk categories represent categories at the second RBS level. The Partnership risk can be managed during the process if there are no contractual agreements with partners signed previously, while the Organizational risk can be affected all the time by reorganizing teams and changing the process formality and execution. A neat process structure enables the mitigation of Organizational risks in the sequential PD process, while this process structure is not so strictly defined in the spiral PD process. An unclear process structure in the spiral PD process entails hard management effort. In both mapping processes, risks included in the Nature category, which emanate from the environment, are uncontrollable. External Financial and Social groups of risks are impossible to control, as a result of external source, which also cannot be directly influenced. Apart from Organizational risk which exists at several management levels, all these risks occur at the levels of a company and upper management.

To emphasize the difference between processes, Consumer feedback and Demand change risks were intentionally left out from this group. While spiral processes are suitable for managing these types of risk, sequential processes are not. In the spiral PD process, the same risk will be encountered again and, on the basis of new information, risk mitigation will be made possible. The spiral PD process addresses these risks and Immature technology risks, closely integrating stakeholders [3]. Demand change risk can be reduced by early contracts as stated in [36]. An analysis of competition actions gives a possibility to intervene and react to Competition risk. These Market risks cannot be affected by a sequential process carried out

afterwards as a result of inflexible reviews, while the spiral PD process allows a company to plan iteration and thereby to mitigate the Market risk in subsequent cycles.

Financial feasibility and Product pricing risks depend on the management planning effort at the beginning of development. According to the budget and financial scope, but also to management skills, risks will be or will not be attenuated.

In the conceptual phase, decreasing the likelihood of Intellectual property risk is made possible by searching thoroughly patent and trademark databases. The use of norms and standards can hinder Legislative risks in later phases. In both process types, these risks are not addressed, but it is assumed that they are very similar to Technical risks in the context of their identification and treatment. Execution of the above-mentioned procedures and checking during continuous design reviews can significantly decrease the possibility of regulatory risk occurrence. The whole group of Regulatory risks emerges at the design team level.

Colours suggest the suitability of PD process types for identified risks regarding given possibilities to influence certain risk categories and subcategories. In the spiral PD process, since there are no classic boundaries between phases, cross-phase and broad iterations are allowed, and therefore risks that belong to the Market category can be significantly mitigated. Consequently, these risks are coloured green in the spiral process and, conversely, red in the sequential process.

In the spiral process, as opposed to the sequential, several boxes were coloured yellow (mostly technical risks). This yellow colour implies the suitability level between green and red, the same as in traffic lights. Control and management of these risks mostly depend on the management effort and how well reviews are executed. This clearly shows a connection between management and flexibility since they are strongly positively correlated as a consequence of a better "control" over the critical points in the spiral PD process.

Comparing these two process types, it was very important to consider differences in model phases and subphases. Namely, the sequential model that was used in this research was more specific and more detailed in comparison with the spiral one. Regardless of the level of detail of these two process models, some conclusions can be reached. External risks cannot be adequately mapped in both process types since their potential risk sources cannot be precisely defined and strictly tied to a particular phase. Other risk categories were assigned to specific phases and risk maps provided an interesting insight into product development risks since various risk categories are differently addressed by these two process types. According to the most important or most frequent risk categories for some company or project, a suitable process type can be chosen.

4. Validation

The objective of validation was to prove the accuracy of risk mapping in two different PD process types. In order to ensure proper validation, we had to collect and analyse the experts' feedback. Among several research strategies which could be used for collecting feedback information, survey methodology was chosen for two reasons. Firstly, survey methodology is usually used for verification rather than for discovery and therefore researchers should already have an idea of the result prior to conducting the survey. Secondly, this approach seeks for common relationships across organizations to provide general statements about the object of research, which makes it suitable for this study. A drawback of the survey is rigidity to discoveries made during data collection. Once the survey has started, little can be done to influence the survey content (adding content to the questionnaire or replacing a question) [11].

The applied survey method was an e-mail questionnaire which was based on empirical evidence and theoretical assumptions reported in the literature. The questionnaire consisted of 5 closed-ended (multiple-item) questions dedicated to the frequency and appearance of different risk categories. Emphasis was put on the multidisciplinary and the socio-technical perspective of risk management within an organization rather than strictly on the reliability and the safety aspect.

The questionnaire was constructed using the online surveying tool FormSite®. Then, it was distributed electronically via mail (with attached link). As a consequence of the rigidity of survey approach, the initially made questionnaire was tested on a small number of respondents (N=4) in order to clarify certain questions according to the received feedback.

The questionnaires were simultaneously sent to companies whose main preoccupation is software development and to companies that are developing mechatronic devices. This survey was conducted in companies of different sizes, from small (barely a few employees in development) to large companies (several hundreds employees in development). The total number of the sampled companies was 180. The companies were found in the official list of companies under the jurisdiction of the Croatian Chamber of Economy (under the previously mentioned categories). Majority of respondents had a technical background and they held leadership positions in their companies (directors). Besides the original message with the invitation to participate in our survey, two reminder messages were sent to increase the response rate, and finally 54 questionnaires were collected during the period February 2012-May 2012. In the invitation and reminder mails, anonymity of each respondent was guaranteed to obtain better and more realistic results. The final response rate was 30%, which is reasonable, considering the survey type (mail questionnaire).

Table 1 Classification of survey respondents

Software companies	Institutes	Mechanical engineering companies	
		More than 50 employees	More than 100 employees
20	14	8	12
		Overall number of respondents	54

The online tool Formsite (www.formsite.com) enabled the collection of responses which were later statistically analyzed. The variables used in this study were qualitatively determined by a 5-point ordinal Likert scale which is often used in surveys [e.g. 22]. The use of relative scales is a practical way to assess the frequency and importance of risk categories. Thus, different risks categories were made more comparable. The original questionnaire used for the survey can be found in the Appendix.

In the first part of the questionnaire, identified and mapped risk categories (from RBS) were listed to assess their frequency and importance in the PD process. **Technical** (Frequency: M=3.70, SD=0.88; Importance: M=4.31, SD=0.72) and **Market** (Frequency: M=3.96, SD=0.91; Importance: M=4.29, SD=0.57) risk categories were recognized as the most frequent, but also as the most important risk categories within the PD process (Figure 6 and Figure 7).

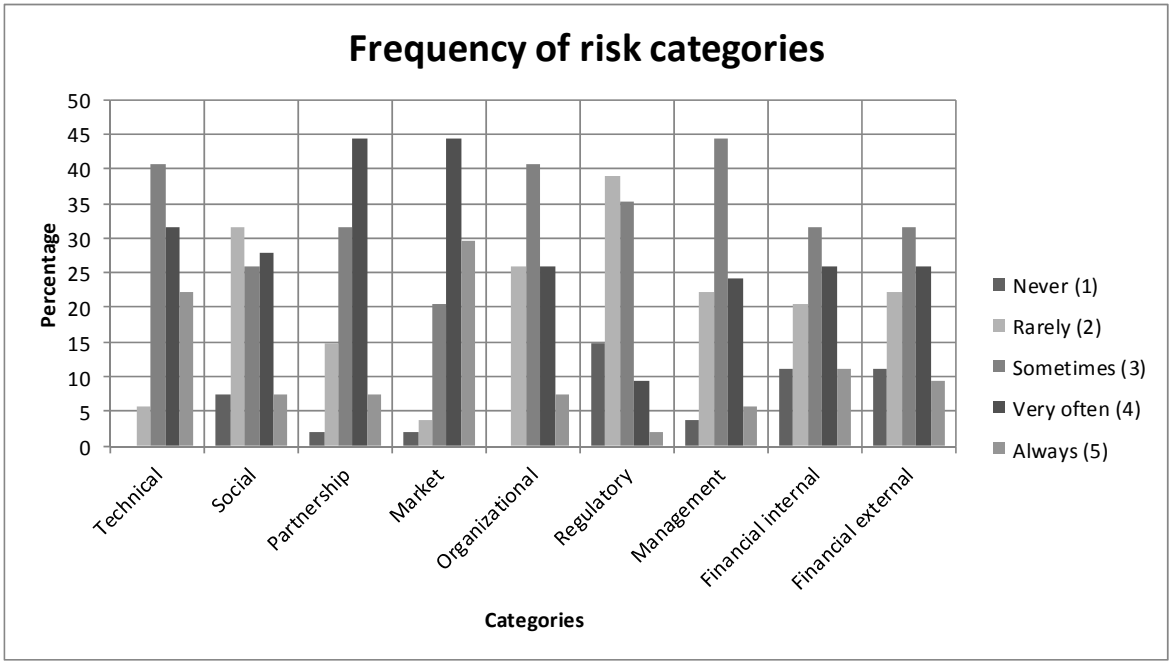

Fig. 6 Frequency of appearance of risk categories in the PD process

Social (Frequency: M=2.96, SD=1.09; Importance: M=3.20, SD=1.13) and **Regulatory** (Frequency: M=2.44, SD=0.92; Importance: M=3.22, SD=1.02) risk categories were perceived as the rarest and the most unimportant risk categories. Results also indicate the high overall importance of all risk categories, since *Important* was the most frequently selected response.

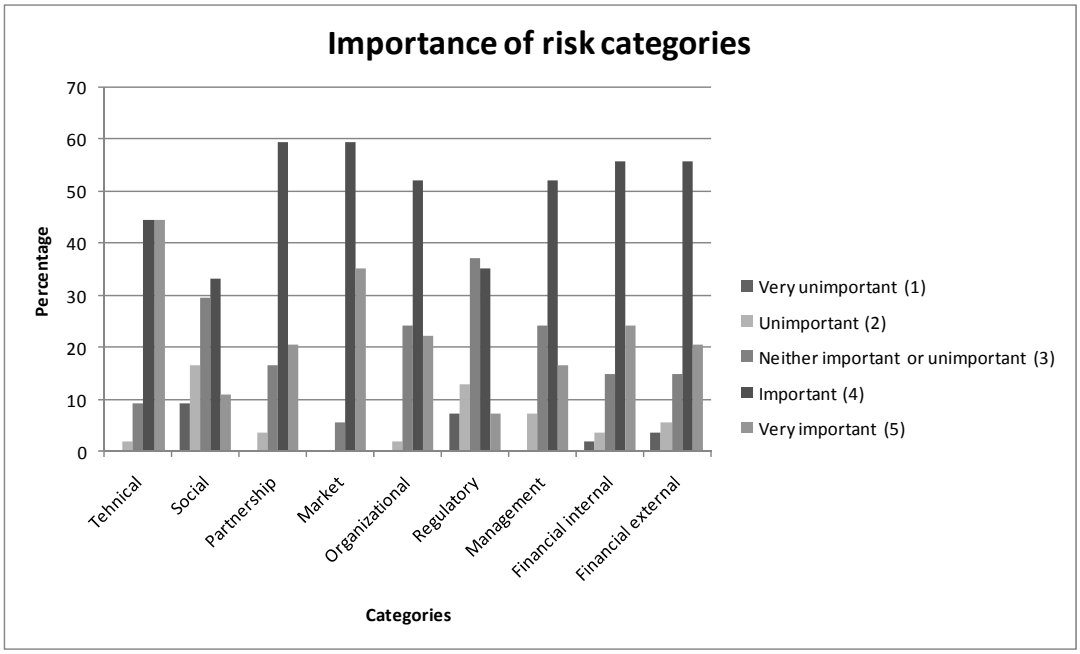

Fig. 7 Importance of risk categories in the PD process

As respondents indicated (Figure 8), in general, the greatest proportion of risk categories is perceived in the **Planning** phase of the product development process (56.6%), but the maximum value of the individual risk category is assigned to the **Technical** risk category within the **Embodiment** phase (66.7%). Observing value changes within the same

risk category (but also among different categories), one should notice the decreasing trend in the appearance of certain risk categories (**Social, Market, Organizational, Management**).

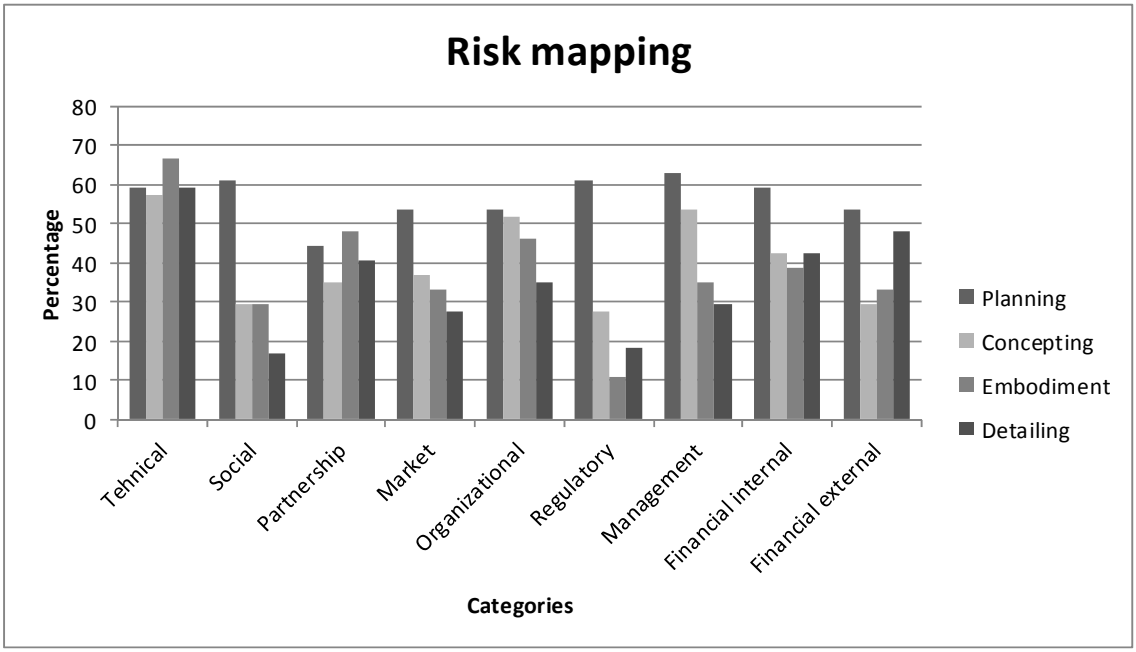

Fig. 8 Risk mapping in the PD process

5. Discussion

Feedback from companies highlighted deficiencies of understanding the risks. From the received responds, we may conclude that technical departments within companies are not familiar with risk management methods or their awareness of the need to cope with risks is still very low. As a consequence, respondents encountered many problems while answering the questions about the mapping of risks.

In general, all risks categories were perceived as important, which indicates the need for systematic and conscious risk management within the company. Technical and Market risk categories were perceived as the most important and frequent, while the frequency of some other categories was considerably ignored. Easier detection of the Technical and Market risk categories contributed to their higher importance and frequency values. Also, the fact that the survey was conducted within technical departments probably caused higher values for Technical risks across all phases of the product development. Outside the respondents' domain, Social and Regulatory risks were perceived as less important and frequent, although their occurrence was clearly emphasized in literature and therefore they should not be ignored and forgotten.

Although risk maps presented in this paper were mostly confirmed within the context of surveyed companies, the sample has to be increased and additional statistical analysis is needed. The overall decreasing trend in most categories across phases suggests a lower level of risks in later phases, but this observation may stem from the fact that the risk identification is mostly conducted in the earlier phases of the development rather than iteratively during the process as it would be expected.

It should be mentioned that this comprehensive research was subject to certain limitations. In every company, only one person (possibly she/he consulted with colleagues) participated in the survey, resulting in a rather narrow perspective. Furthermore, the questionnaire was sent only to technical departments, not including the management, sales,

and other perspectives. All limitations which are related to survey approach should also be considered. To get more precise and more useful answers, the number of survey respondents must be increased. Further statistical analysis has to be done in order to fully explain differences between different groups of respondents (for example, according to the main preoccupation of the companies). Also, some other research strategies should be used (like semi-structured interviews and case studies) to better understand different risk appearances within PD processes.

6. Conclusion and future research proposals

Based on the RBS that was created for product development, risk categories and subcategories are assigned to various phases in two different product development process types, sequential and spiral. Mapping of identified risks, which is presented in this article, provides information about the position of certain risk categories and subcategories in the product development process. In addition, it could possibly facilitate risk identification in the future.

For the validation of proposed risk mapping, survey methodology was used. The feedback from companies highlighted the need for a systematic and conscious risk management within companies since relatively high importance of all risk categories was clearly recognized. Technical and Market risk categories were perceived as the most important and frequent, while the frequency of some other categories was considerably ignored. Risk maps presented in this paper were mostly confirmed within the context of surveyed companies, but in order to obtain more information about differences between various groups of respondents, the sample has to be increased and a detailed statistical analysis has to be done.

In a future research, it is planned to provide recommendations for selecting risk identification methods according to the risk category in product development. Furthermore, modifications to the existing PD processes could be proposed on the basis of the characteristic risk categories and subcategories to define the rigidity and narrowness of certain PD phase iterations. Customization of the product development process regarding certain risk categories in the form of iteration planning would be a next logical step in the improvement of the product development process. One of possible research directions is to analyze risk management methods in other domains (especially for non-technical risks) and to adapt the same methods to the needs of product development. Further research into the sequential and spiral PD approaches with an emphasis on risk perspective will be undertaken in order to recognize interactions and correlations between risk categories and within a risk category. Mapping of product development risks according to some other criteria would be beneficial for a better understanding of risks and their description.

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