INTERNATIONAL DESIGN CONFERENCE - DESIGN 2012
Dubrovnik - Croatia, May 21 - 24, 2012.

MAPPING RISKS IN PRODUCT DEVELOPMENT

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Keywords: risk, product development process, risk identification

1. Introduction

The main interest of this paper is to increase the understanding on various groups of risks in product development (PD) and to perform a comparative study on how the risk emerges in certain phases within PD processes. The objective of the presented research is to improve risk identification in product development using Risk Breakdown Structure (RBS) method [Hillson 2002] and mapping recognized risks on the phases of the sequential and recursive PD processes. Risk maps of PD processes should provide insight in frequency and meaning of certain risk categories and establish the basis for a valid comparison of different types of PD process. To accomplish the objective, presented research involves broad literature review of publications in area of risk perception, identification and management in product development, and case based validation. Validation of the results was based on qualitative and descriptive approach.
The following section of this paper includes description of the research background and the related work. It consists of short discussion about risk models, risk management and risk identification. Results of the synthesis are presented in section three including creation of the RBS for the general product development process and mapping of identified risks on different product development process types. After description of the case studies used for validation of the synthesis results, this paper finishes with conclusions and future work proposals.

2. Background and related work

2.1 Risk models and definitions

Many definitions of risk in product development are presented in the literature, but presented research adopts the one provided by Smith "the risk is the possibility that an undesired outcome disrupts your project". Reason for choosing this definition, among others, is strict perception of a risk in a negative way, as a threat, despite the fact that certain standards [PMI 2004], [PRAM 2004], [IRM/ALARM/AIRMIC 2002] comprehend risk as a term that could represent opportunity.
This definition implies two components of the risk, probability and impact. To describe factors which influence these components, risk model should be used. Risk models give insight into nature of risk and elicit common understanding of risks in PD. Even though there are few risk models applicable in product development process, Standard Risk Model is the most appropriate since all other models could be derived from it [Smith and Merrit 2004]. Standard Risk Model, which upholds cause – effect relationships, is presented in Figure 1. The model is divided in three portions: Probability, Impact and Drivers. Critical portion of this model are drivers, because their existence implies risk event or impact occurrence. By properly adjusting the drivers, prevention and contingency plans are accomplished, which should prevent risks from happening.

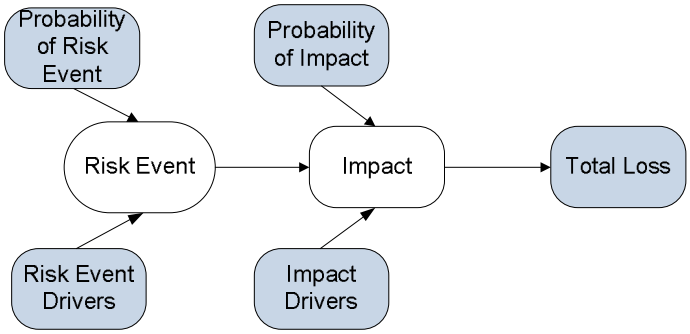

Figure 1. Standard risk model [Smith and Merrit 2004]

2.2 Risk management

In reviewed literature, Risk management approaches are consisted of identification, analysis, evaluation, treatment and monitoring of risks [PMI 2004], [Oehmen et al. 2010], [Bassler et al. 2011], [Smith and Merrit 2004]. Methods which are used for specific risk management phases are shown on Table 1. Some authors provide risk management approaches with various levels of details and also, some additional activities as planning in advance, prioritization etc. [Ferreira and Oligari 2005], [Raz and Hillson 2005].

Risk identification is a phase of recognizing and defining risk for which heuristic, analogical and analytical methods can be used [Grubisic et al. 2011]. During risk analysis, impact and probability of risks should be valued and estimated so that in the next step they could be properly treated and mitigated according to risk strategies [Gericke et al. 2009]. Finally, risks need to be continually reviewed and monitored to maintain desired project's course.

Literature review indicates that for risk identification, risk analysis and risk evaluation exist certain amount of methods, but there is a gap in existing literature regarding risk treatment and monitoring phases as indicated in Table 1 [Bassler et al. 2011], [Oehmen et al. 2010]. Methods for risk monitoring are mostly too general and not easily applicable.

Table 1. Risk management methods

Risk identification	Risk analysis	Risk evaluation	Risk treatment	Monitoring and review
Brainstorming	Likelihood and impact (FMEA; FTA; QFD)	FMEA	Only high-level strategies	Number of risks
Delphi	Real options theory	Values for real options	Knowledge management	Risk reduction profile
QFD	DSM	Risk matrix	Technology validation	Top 10 Risk Ranking
FMEA	Monte Carlo simulation	Probability distribution		Risk metrics dashboard
FTA/ETA	Delphi			Overview of action plans
Checklists	Expert surveys			
Expert interviews				

In this research, particular emphasis of this study is placed on risk identification. According to some authors [Smith and Merrit 2004], [Charette 2001], risk identification, as initial phase of risk management, is considered probably as the most important step because unidentified risks cannot be adequately treated. All aforementioned risk management methods and tools for product development rely on identification phase implying necessity for clear and comprehensive overview of risks. In this paper, created RBS should ensure complete and systematic identification in product development.

2.3 Risk identification and breakdown structure in PD

Risk identification is not straight-forward process, but strongly iterative because it is hard to identify all possible risks. Some risks are unforeseeable and none of the methods will be useful for identifying them. Nowadays, numerous methods can be found for risk identification [HSL 2005], [Smith and Merrit 2004], [PMI 2004] such as creative methods, checklists, FMEA, FTA etc. Hillson in 2002 claims that "best method" cannot be found, but their combination can be used for certain project.

Although there are plenty of identification methods, a proper procedure for choosing them regarding various types of development projects is abundant. Only the work of [Ferreira et al. 2011] tackles selection of risk identification methods. They recommended a procedure (Table 2) for choosing an

adequate identification approach defined by criteria such as product design and project management maturity levels, product innovation degree and project team. They made a classification of methods regarding their characteristics and divided them into three, already mentioned, categories: analogical, heuristic and analytical.

Table 2. Recommendations for selecting appropriate risk identification method [Ferreira et al. 2011]

Criteria / Typology	Product Design and PM Maturity	Product Innovation	Project Team
Analogical	3+	Adaptable/Alternative	+
Heuristic	1+	Innovative/ Adaptable	++
Analytical	3+ Product design and $(PM)^2$ - Key PM Processes and Focus Areas	Innovative	+++
	4+ $(PM)^2$ - Organizational		
+++: very important ++: important +: less important			

The risk identification phase often results in an unstructured risk list that cannot help the project manager dealing with risk management. For that reason, structure could be helpful for describing risks under observation. Structure confirms that generated information is understood and presented in a standardized way. For structuring risks in product development, Risk Breakdown Structure (RBS) method can be used.

RBS is in a literature 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" [Hillson 2002]. Simply, it is a hierarchical structure of possible risk sources, to be more practical, a checklist [Oehmen et al. 2006]. In the literature [Tummala and Burchett 1999, Chapman 2001] there are several examples that resemble RBS, but they were not named that way. These risk structures were focused on particular domain and research, and for that reason, in this paper new RBS is made for general product development risk structure. RBS was also made for Generic Project [Hall and Hulett 2002], but it is doubtful if it could have any practical use since it is high-level and too general for application.

Main benefit of the RBS is aiding risk identification, encouraging participants to identify and elicit risks under all categories, since its completeness and universality. RBS, as a prompt list or a checklist, can enhance and facilitate brainstorming sessions or interviews by revealing potential gaps in risk identification. It could be used for assessment and comparison of different projects. Also, lessons learned should help to perceive recurring risks and, accordingly, to act proactively towards risk in following projects [Hillson 2002].

2.4 Product development processes – risk management perspective

Product development process is a set of activities which starts with understanding the market opportunity and ends with production, sales and delivery of the product. [Urlich and Eppinger 2003] Risk management, when addressed in project management, should help to cope with dynamic technological and market environment and have its eminent role in product development [Smith and Merrit 2004]. Due to possible cost overruns, schedule delays and insufficient product quality, there is a significant need for proactive risk management.

In the literature, various types of product development processes can be found. The most commonly used and applied are sequential PD processes whose main representative would be Stage-gate, also known as waterfall process. Stage–gate acquires linear proceeding and the continuation of the process to the next stage is determined by positive evaluation at the preceding gate (kill-go decision). Therefore, it strongly depends on advance planning and proceeds well when customer requirements are stable; otherwise expensive cross-iterations are required.

Next type would be recursive PD processes which are determined by feedback loops and overlaps of different PD stages. These characteristics also define spiral development process which is mostly used

in software industry because of its working effectiveness in dynamic market environment. Some authors [Boehm 1988] represent spiral PD as risk-driven approach because of its flexibility even in later phases.
In reviewed literature, Oehmen and Seering in 2011 made significant research in which Risk-Driven Design with corresponding four principles is presented: 1. Creating transparency regarding design risks; 2. Risk-driven decision making; 3. Minimizing uncertainty; and 4. Creating resilience. According to those principles, Bassler et al. in 2011 compared product development approaches. As stated in their findings, both of these process types aren't focusing on the resilience of design system which would enable risk tolerance buffers. Furthermore, they are not transparent regarding design risks and have to improve their compatibility with identification methods. Risk-return analysis should be conducted at the start of development process (planning) to enable risk-driven decision-making [Bassler et al. 2011], [Oehmen and Seering 2011]. Every approach addresses certain aspects but some remain intact.
Comparison of spiral and linear PD process types was seen in [Unger 2003], [Unger and Eppinger 2009] suggesting a way of characterizing PD processes. Main characteristics of PD process were expressed with review and iteration parameters. With these metrics, recursive development process can be described as cross-iteration process with flexible reviews. Conversely, sequential development process allows narrow iterations and prescribes rigid reviews. Afterwards, on this basis, PD process design method was proposed which should help companies in planning and selecting PD processes regarding their risk profile [Unger and Eppinger 2010].
Oehmen and Seering in 2011 are discussing uncertainty types in product development, but mapping should be a step forward in describing risk characteristics. Understanding positions of risks in PD process, could also facilitate assigning risks to iteration cycles and reviews [Unger and Eppinger 2010]. In following section, sequential and recursive product development process types are compared according to risk mappings on certain product development phases. Assigning risks to PD phases should lay the groundwork for comparison of these PD process types. To validate mappings, questionnaire was sent to development companies to survey participants in product development about risk occurences.

3. Results

3.1 Risk breakdown structure

This RBS was made according to rules for creation provided in [Hillson 2002]. After extensive literature review and analysis of some risk structure examples, a basis for tailoring RBS for PD was established. The idea behind of the created RBS, in comparison with others (section 2.3.), is to develop RBS for product development process emphasizing design phases. This RBS should provide us with unique view of the risk sources in PD, decomposing a product development risk into layers of increasing detail.
As is shown in the Figure 2, 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 originated from the PD environment). This first-level classification of PD risks is the most natural and is already seen in literature [Hillson 2002]. These two categories are further subdivided in subcategories. Criterion for classification was type of risk source which determined position within particular subcategory. Four levels were estimated as a satisfactory granularity, but also high enough to elude various risk source problems. Thus, overlapping of subcategories on lower levels, as a result of multiple different sources causing the same risk, can be avoided. As can be seen on Figure 2, some risk categories are decomposed to third level due to the fact that these risks are detailed enough for the purpose of this research (e.g. Social risk).
Internal risks categories include Management, Financial (internal), Technical and Organizational risk. Management risks are a group of risks, which is encountered by upper management, and include corporate strategy and contractual risks. Financial risks are related to financial feasibility of a project, and organizational risks are connected to organization of processes and personnel. Technical risks are risks connected with technical feasibility and technical quality of the product.

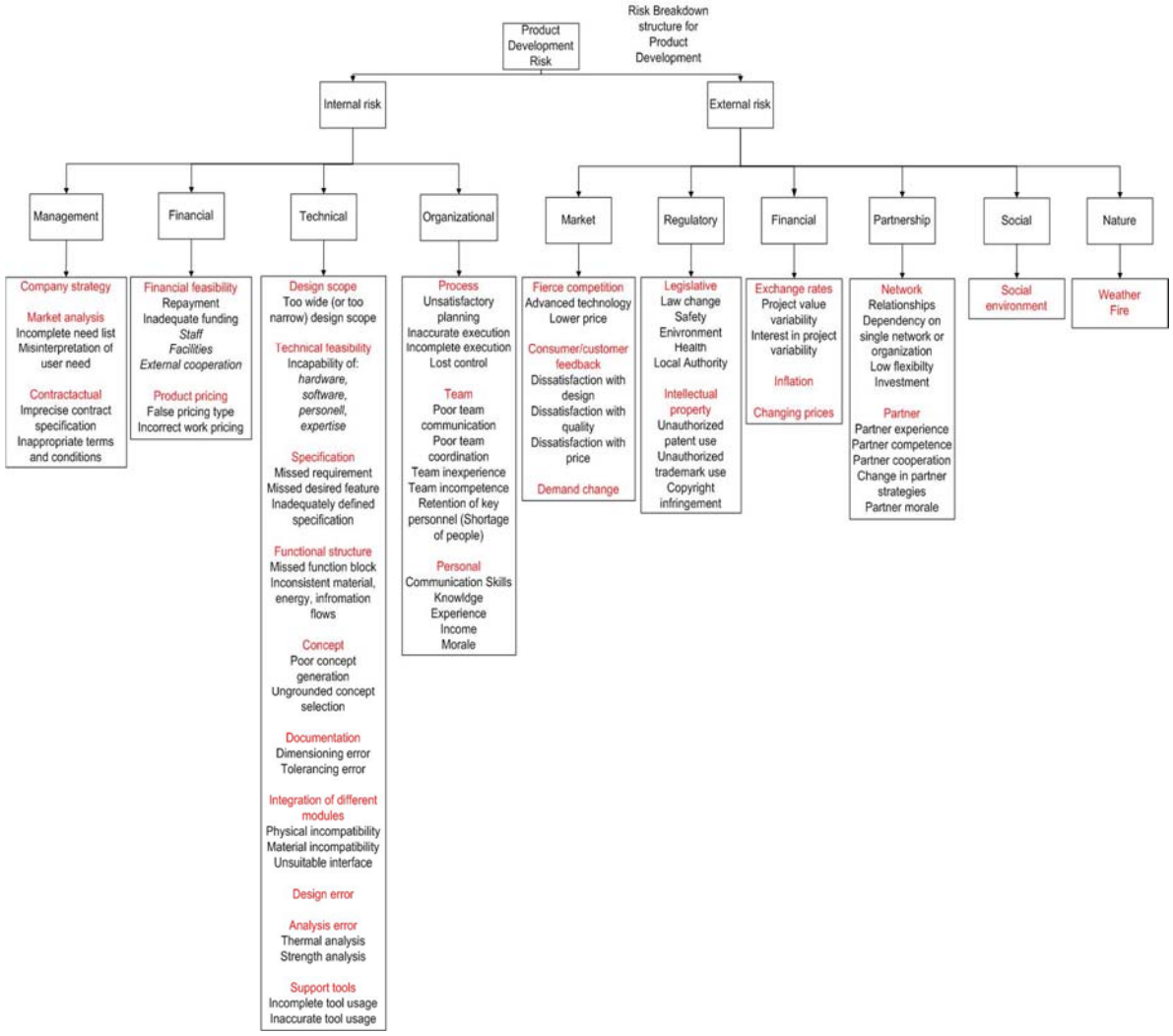

Figure 2. Risk breakdown structure for product development

External risks are divided into six categories: Market, Regulatory, Financial (external), Partnership, Social and Nature risk. Financial, Social, Nature and Regulatory risks are uncontrollable categories of risks representing surrounding environment. These categories cannot be controlled because they are exposed to various exogenous factors. Market risks are, in many projects, the most important category encompassing all risks associated with customers and their demands. Partnership risks arise from relationships with partners and within partner networks. Subcategories, on lower levels, are not final since no RBS is complete, as a consequence of wide spectrum of risks in different fields of product development.

3.2 Mapping risks on product development processes

The next step in the research was mapping of the risks to the two types of PD processes, sequential and recursive. Sequential process model that is presented in Figure 3 is used from the [Otto and Wood 2001] which resembles activities in linear product development process. Figure 4 shows a generalized version of spiral process developed by [Ungur and Eppinger 2009] which was used for the second mapping process. This mappings are based on comprehensive literature review and, afterwards, were confirmed by survey results.

As shown in Figure 3 and 4, different categories of risks, discovered and classified by RBS, are mapped regarding their appearance in sequential and recursive PD processes. Technical risks are scattered on both pictures and it seems that in almost every phase of PD process they may be encountered in both process types. Technical risks, which are mapped on these two models, belong to

third and fourth level of the RBS. Strict and rigid reviews in sequential processes force early freezing of specifications, while in recursive process they remain flexible resulting in poorer control of technical risks [Ungur and Eppinger 2009]. During all phases, technical risks are constituents of product development and they may appear especially on operative levels where designers try to decrease their effect on the final outcome.

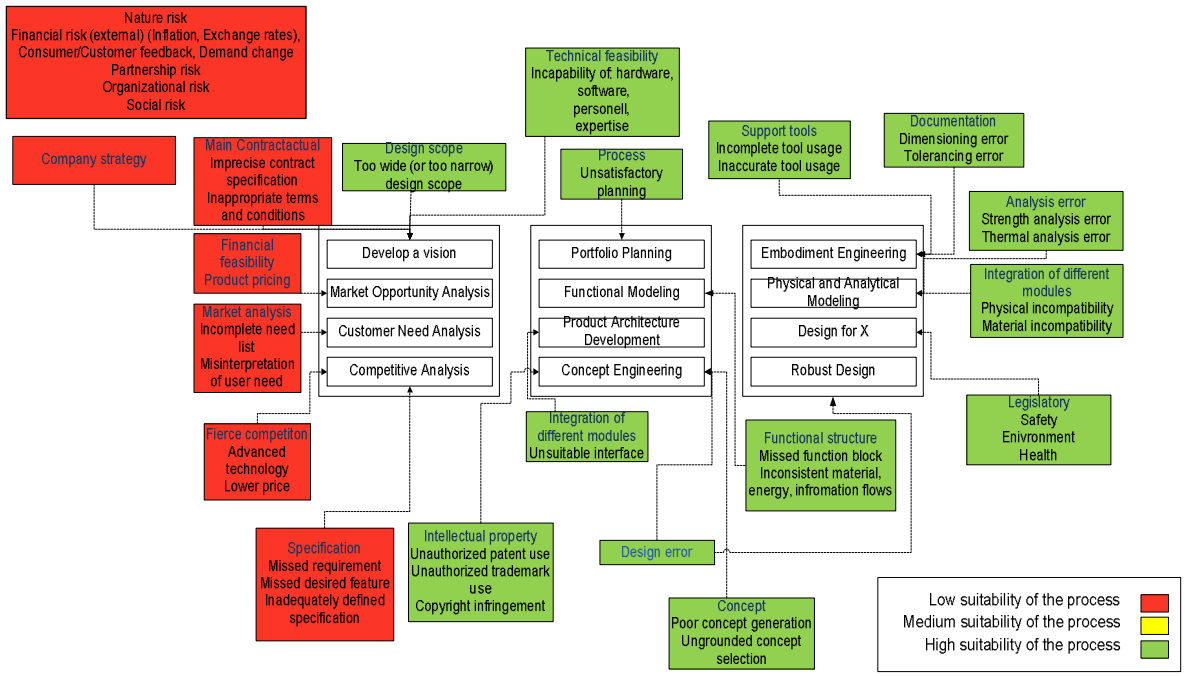

Figure 3. Mapping on sequential product development process

Group of risks, that are present during the whole sequential and recursive processes, is separated in a box that is located in upper-left corner of the pictures. This group encompasses risks which cannot be directly mapped to certain phase because they are omnipresent and they cannot be linked to any specific phase. Group is consisted of Nature risk, External Financial risk, Partnership risk, Social and Organizational risk which all represent categories on second RBS level. Partnership risk can be managed during the process if there were no contractual agreement with partners in advance, while Organizational risk can be influenced all the time by reorganizing teams and changing the process formality and execution. Neat process structure enables mitigation of Organizational risks in sequential PD process, while in recursive PD process this process structure is not that strictly defined. Unclear process structure in recursive PD process entails high management effort. In both mappings, risks included in Nature category, which emanate from environment, are uncontrollable. External Financial and Social group of risks are impossible to control, as a result of external source, which also cannot be directly influenced. Apart from Organizational risk which exists on several management levels, all these risks appear on a company and upper management level.

To emphasize the difference between processes, Consumer feedback and Demand change risks were intentionally left out from this group. While recursive processes are suitable for managing these types of risk, sequential processes aren't. In recursive PD process, same risk will be encountered again and on account of new information, risk mitigation will be possible. Recursive PD process addresses these risks and Immature technology risks closely integrating stakeholders [Bassler et al. 2011]. Demand change risk can be reduced by early contracts as well [Ungur 2003]. Analysis of competition actions gives possibility to intervene and react on Competition risk. These Market risks cannot be affected in sequential process afterwards as a result of inflexible reviews, while recursive PD process allows company to plan iteration and thereby to mitigate Market risk in subsequent cycles.

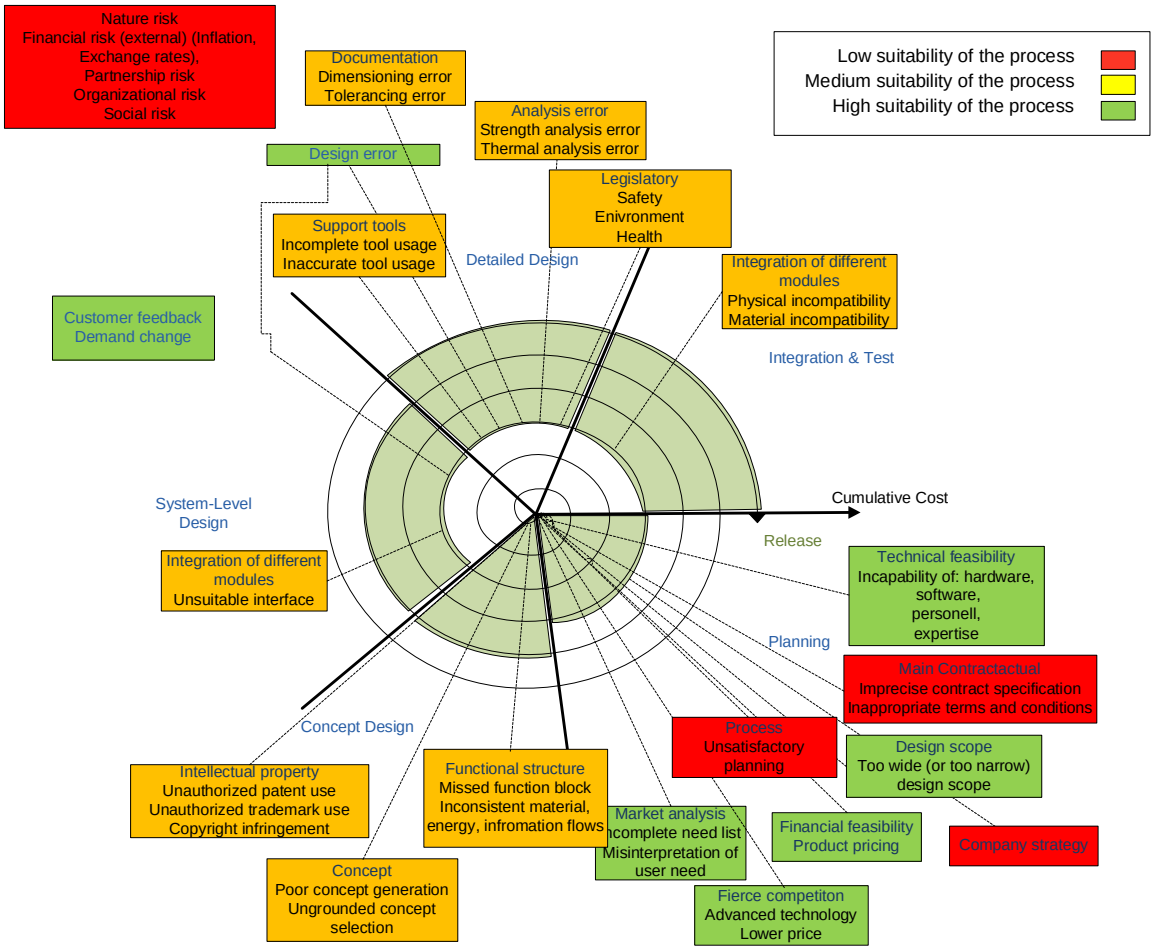

Figure 4. Mapping on recursive product development process

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

In conceptual phase, decreasing of likelihood of Intellectual property risk is possible by adequately and consciously searching patent and trademark databases. Norms and standards usage can hinder Legislative risks in later phases. In both process types, these risks are not addressed, but assumption is that they are very alike Technical risks and depend on review rigidity. Whole group of Regulatory risks is emerging on design team level.

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

In recursive process, as opposed to sequential, several boxes were colored yellow (mostly technical risks). This yellow color implies suitability level between green and red, reminding of traffic lights. Controlling and managing these risks are mostly depending on management effort and how well reviews are executed. This clearly shows a connection between management and flexibility, since they are strongly positive correlated as a consequence of better "control" over the critical points in recursive PD process.

Comparing these two process types, it was inevitable to avoid differences in model phases and subphases. Namely, sequential model that was used in this research was more specific and more detailed in comparison with recursive one. Regardless of 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 interesting insight into product development risks since various risk categories are differently addressed by these two process types. According to most important or most frequent risk categories for some company or project, suitable process type can be chosen.

4. Case study and discussion

Objective of the validation was to approve mapping of risks on two different PD process types. Among several research strategies, survey method was chosen for collecting data for two reasons. Firstly, survey method is usually used for verification rather than for discovery and therefore researchers should already have an idea of the result prior to the survey. Secondly, this approach seeks for common relationships across organizations to provide general statements about the object of research, what makes it suitable for this study. Deficiency of the survey method is rigidity to discoveries made during data collection. Once the survey has initiated, little can be done to influence on survey content (adding content to the questionnaire or replacing a question) [Gable 1994].

Selected survey method was a mail questionnaire which was based on empirical evidence and theoretical assumptions reported in the literature. The questionnaire consisted of 8 open-end questions and 2 closed-ended questions about risks and risk mappings in companies. Significant part of questionnaire is dealing with frequency and appearance of different risk categories. There were also few common questions about application of risk management principles (emphasis on risk identification) during development.

Questionnaire was 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 hundred employees in development). This survey was conducted preliminary on small number of respodents, while extended and final survey is still open. After closing extended survey, all results will be published and reported.

Respondents, from companies which use sequential PD process, mostly identified Technical and Market risks in their PD. These two risk categories were mapped exactly as they were presented on sequential model (Figure 3). Respondents also identified other types of risks (Organizational, Financial…), but they could not define their position of occurence. It is interesting to note that Financial (external) and Financial (internal) risk categories were recognized as the most important in these companies, with a particular emphasis on Exchange rate change as a consequence of the current global economic situation.

Respondents, from companies which use recursive PD process, identified Market and Organizational risks. This was expected, since recursive process is suitable for managing Market risks closely integrating stakeholders, as indicated in previous sections. Financial (internal) risks were recognized in company internal projects, but the most frequent risk category Market appears in all external projects. In some PD processes, Technical risks were not identified at all, while in others, they were mapped on whole process and were very significant. Furthermore, Partnership risk category was identified as integral part of every recursive and sequential development process. Social and Intellectual property risks were not identified in any company, neither in sequential nor in recursive PD process.

This research was subject to certain limitations. In every company, few people participated in survey, resulting in narrow perspective. Respondents belonged to the same company structure level. Furthermore, survey was sent only to technical department, not including management, sales and other perspectives. All limitations which are related to survey approach should also be considered. To get more detailed and more useful answers, the number of survey respondents still must be increased. Also, some other research strategies should be used (like semi-structured interviews and case studies) to further understand different risk appearances within PD processes.

Feedback from companies highlighted deficiencies in understanding the risks. From answered questionnaires is obvious that companies are not familiar with risk management methods or their knowledge level is still very low. For risk identification they mostly use creativity methods in irregular time intervals, unaware of the advantages of other identification methods for certain risk categories. Also, these creativity methods are not even properly used. Since their understanding of risk is low,

they are not focused on the distinction between risks and their potential effect. Risk identification sessions usually result in unstructured risk lists which are not reusable, although lessons learned already proved their applicability. Risks are identified only at the start of the project, ignoring the fact that risk identification should be iterative process. As a consequence of the above-mentioned, respondents encountered many problems while answering questions, especially about mapping of risks.

Companies are still not implementing risk management in their processes methodically and systematically. In companies, there are no clearly defined guidelines or standards for managing risks in PD and respondents did not have any formal risk management training. Risk management is approached in terms of individual reasoning, intuition or previous experience. In general, companies are still unaware of the benefits and assistance which can be provided by risk management.

5. Conclusion

Mapping of risks, which is made in this article, provide information about position of certain risk categories and subcategories in process and could facilitate risk identification in future. With this information, identification methods could be selected according to encountered risk category in different types of the PD processes. Of course, our research is at the beginning. In a future work it is planned to provide recommendations for selecting risk identification methods accordingly to the risk category in product development. Additionally, linking risk management methods with certain risk categories would considerably facilitate application of risk management principles in companies. One of the possible research directions is to analyze risk management methods in other domains (especially for non-technical risks) and to adapt these same methods for the needs of product development. Further research of sequential and recursive PD approaches with emphasis on risk perspective will be continued in order to recognize interactions and correlations between risk categories and within risk category. Mapping of product development risks according some other criteria would be beneficial for better understanding and description of risks.

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