

PRAGMATIC RISK ASSESSMENT APPROACH FOR PRODUCT DEVELOPMENT

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ABSTRACT

The paper proposes a practical assessment approach to estimate duration of the product development process incorporating risk management principles. Risk assessment, as a crucial part of risk management process, is a systematic process for estimating the risk level of previously identified and recognized risks. Currently, the best-known relationship in risk assessment is that risk level equals the product of two factors – likelihood and impact. The proposed approach treats these factors as random variables with triangular probability distributions in order to mitigate biases due to subjective risk estimation. Based on a literature review, the approach considers probability functions assigned to estimated values which together with Monte Carlo simulation avoid fixed single-point estimations and deterministic simulation issues. Relating this kind of assessment with previously established risk mapping on the product development process broadens insight about the influence of risk on the process metrics. Since, risk assessment is still mostly approached in terms of individual reasoning, intuition or previous experience, providing a practical method for assessing risks can enhance and facilitate the usability of risk management principles in product development companies.

The proposed approach is illustrated using an example, which involves an automated car washing facility product development process.

1 INTRODUCTION

The aim of this paper is to propose a practical risk assessment approach as a continuation of product development risk mapping to estimate the duration of the product development process incorporating risk management principles. Probably, the best-known relationship in risk assessment is that risk level equals the product of two factors – likelihood and impact [GX09]. Connecting this kind of assessment with previously defined risk mapping gives insight into risks influence on process metrics. After identifying risks using the Risk Breakdown Structure accomplished for product development [SSS+12], the next step, which is tackled in this paper, is to find a suitable way of assessing the risks to gain more information and to enable adequate mitigation strategies. In order to lessen the bias in risk value estimation, triangular probability distributions are assigned to previously estimated values of risk likelihood and impact.

In order to establish a theoretical basis for proposing a new method, this paper begins with a description of the research background and the related work section discusses risk assessment, risk mapping and probability distributions. The practical approach for assessing risks within the product development process is proposed in Section 3. In order to exemplify the proposed approach with a case, Section 4 comprises an illustrative example of an automated car washing facility development process focusing on project level risks. Being narrow in iterations and with rigid reviews, the illustrative example's product development process has been selected on purpose to put forward the justification of the proposed risk assessment approach. The paper rounds up with a discussion of implications and conclusions.

2 RESEARCH BACKGROUND AND RELATED WORK

According to the results of a survey [SSS+12], risk management is still mostly approached in terms of individual reasoning, intuition or previous experience and providing a practical method for assessing risks can enhance and facilitate the usability of risk management principles in product development companies. In order to propose a practical approach that could be accepted in industry, present practices and recent literature need to be reviewed. In the risk assessment subsection, different methods and assessment examples from relevant literature will be presented in order to introduce the state of the art in this particular research field. As the main terms of risk level calculation incorporated in our approach, likelihood and impact are defined in subsection 2.2. The next subsection ties risk assessment with product development process to define the environment for assessing risks as viewed by our approach. Finally, the last subsection considers probability distributions and their applications in subjective estimations of risk components, with special focus on triangular probability distribution that will be further discussed in this subsection.

2.1 Risk assessment

As a crucial part of the risk management process, risk assessment is a systematic process for estimating the risk level [K06] of previously identified and recognized risks. Deeper understanding of risk impacts and taking more rational risk-based decisions are just some of its benefits, which can be accomplished by acquiring risk event information through qualitative and quantitative risk assessment methods [K06].

Quantitative risk methods make different risks categories and sources more comparable. Risks can be quantified based on individual or group judgments and estimates (of likelihood and impact – described in 2.2), but also based on probability distributions of objective achievements [OBS+10]. Referring to former methods (e.g. FTA, ETA, FMEA [AKA07, SM02]), it is important to emphasize the difficulty of defining general scales which can provide guidance for estimators to accomplish the required accuracy when estimating risks [ODL+06], while latter methods can require considerable resources and years of statistical data [AKA07, H11].

The literature review reveals that research focus is on quantitative methods [OBS+10], although there are still some qualitative risk assessment methods. These methods enhance the understanding of risk, but without numerical values. Some researchers [HH04, H11] think that this group of methods is good enough for acquiring risk information with enough confidence, since it is very important to realize that the process of risk assessment involves subjective judgment at every stage. Although, qualitative methods are straight-forward and easy to use, they are often biased and abounding with uncertainty.

Several relevant research studies on risk assessment can be found in the literature. For instance, Carr and Tah [CT01] developed a formal model for qualitative risk assessment based on fuzzy approach. Choi and Ahn [CA10] established a method for quantitative assessment of impact of risk factors based on concurrent engineering basis using fuzzy theory and Markov processes.

In spite of the above-mentioned issues, risk assessment and its techniques are perceived as useful and efficient in industry, and for that reason, applicability should be one of the main research directions. The approach introduced in this paper combines qualitative and quantitative methods, accentuating the practical perspective of risk assessment. Using both method types, proposed approach decreases the subjectivity of the estimations of likelihood and impact.

2.2 Likelihood and impact

Likelihood can be defined as “a measure of the relative frequency of occurrence of an event, whose values lie between zero (impossibility) and one (certainty), derived from a theoretical distribution or from observations” [C79]. Although originally this is a definition of probability, it seems that it perfectly describes likelihood from our perspective. In our approach, risk likelihood values were defined according to quantitative interpretation of verbal expressions. Hillson [H05] identified range of probability values for the most commonly used verbal phrases in likelihood estimation. Verbal scales can allow users to think in more descriptive terms rather than numeric values (which is accepted as being difficult for some people) and for that reason generic verbal scales were used for valuation

and comparison of risks from different categories or domains. As a drawback, difficulties to differentiate and classify various likelihood values can be perceived in case of very small differences between risk values.

Impact can be defined as “the consequence or potential loss that might result if a risk event occurs” [SM02]. Impact of certain risk can be measured in different ways, however time was selected as an assessment dimension because emphasis is put on project duration. Of course, relations between duration of the tasks (and project in general) and assigned resources exist and provide the possibility of monitoring impact on costs.

The approach in this paper takes risk level as a product of two estimated components, likelihood and impact or $R = L * I$, which presents the most commonly used equation in risk assessment in relevant literature [GX09, SM02, P04]. In order to have consistent and meaningful assessments of risk level, likelihood and impact must be assessed with particular attention. Mapping risks on various product development process levels and afterwards assigning probability distributions to their characteristic estimations (likelihood and impact) can give insight into possible outcomes of the project regarding its delays or cost overruns.

2.3 Risk mapping on different process levels

Understanding of a risk phenomenon is essential for establishing risk mapping on the product development process. According to Smith’s Standard Risk Model [SM02], risk can be decomposed into drivers and events that can be helpful in understanding of term “risk”. Therefore, there should be clear distinction between *risk source event* and *risk impact event* (as defined by Smith) and identification of risk sources is interwoven with identification of risk impact events to fully comprehend the whole risk. The RBS method provides us with a structural view of the risk sources in product development, decomposing a product development risk into layers of increasing detail. As shown in [SSS+12] risks can be mapped on different product development process phases according to their appearances during the process.

To enable risk assessment on different process levels, emphasis should be placed on the very important link between Risk Breakdown Structure [H02] levels and the levels of process decomposition. For this matter we’ll employ process decomposition according to Lindemann [L07] whose process levels can be connected with risks which are identified and recognized with Risk breakdown structures (RBS). This enables us switching between different process levels in order to enable comprehensive risk assessment:

- Strategic process level (generic)
- Project level (rough stages)
- Operational level (interrelated activities)
- Action level (elementary level)

Higher levels of detail in RBS present risks connected with certain actions on lower levels (Operational and Action). During process modelling, emphasis should be put on possibility to model on any process decomposition level in a way that the whole complexity of the product development processes can be encompassed. Nevertheless, in this research we would like to exclude Action level, because dealing with risks on that level is unfeasible at the moment as a consequence of its abstractness. Tasks on lower levels can make this phase extremely burdensome because of difficulties in determination of risk values and for that reason avoiding too fine process resolution is critical regarding efficient risk assessment.

2.4 Probability distributions

A project team can only estimate the probable risk component values and their influence on project duration or cost, because outcomes of the project are known once it is finished [G03]. Therefore, using probability distributions offers a practical way to assess risk without extensive data collection [GX09,

K04]. Recommended probability functions represent the relationship between probability and a certain event [G03]:

$$f(X: Value) = p (X = some condition or value)$$

Probability functions show the distribution of the value according to probability that a certain value will occur. Although, there are many different probability functions, many authors from different fields [KD04] recommend the use of triangular distributions when the underlying distribution is unknown (Figure 1). Also, according to Glickman [GX09], when there is no or little historical data, triangular distributions are usually used for provision of subjective description. They are often used in project management and business processes, but as stated by Johnson [J97] easy to understand and can provide an adequate value approximation in comparison to other distributions. Since triangular distributions can be applied to individual events, durations and costs [G03], they can also be used for risk events.

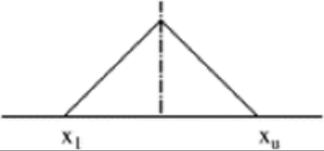
Picture of STD	Mean value	Standard deviation
	$1 / 2(x_l + x_u)$	$\frac{1}{\sqrt{6}} \left(\frac{x_u - x_l}{x_u + x_l} \right)$

Figure 1. Symmetric triangular probability function

Triangular distributions for risk analysis appear as a research topic of certain authors. Joo and Casella [2001] studied triangular distributions from a risk analysis simulation aspect. Khamooshi [K04] suggested usage of different probability functions while evaluating risks in his Project Risk Network. Glickman and Xu [GX09] proposed a practical approach using triangular distributions focusing on variability in risk values.

Since estimations in our approach are subjective, the proposed approach treats likelihood *L* and impact *I* as random variables with triangular probability distributions. These distributions are assigned to the risk component values to include estimation biases, which are an integral part of every assessment session. Due to nature of risk, only one probability distribution type is used because it is difficult to select different probability distribution types according to certain risk category or type. Selected triangular distributions are defined by the minimum, the most likely and the maximum values of the random variable. Allocation of probability distributions represents the central part of this pragmatic approach for risk assessment in product development, which will be introduced and explained in the next section.

3 RISK ASSESSMENT APPROACH

This risk assessment method consists of the estimation of likelihood *L* and impact *I* of every identified risk which allows their influence on the process metrics to be perceived (Figure 2). The qualitative part of estimating these two risk component values is extended with quantitative analysis of probability distributions of likelihood and impact in order to gain a probability distribution of the product development process duration including a risk management perspective.

The proposed approach is applied at risks that were previously identified and recognized using the Risk Breakdown Structure (RBS) for product development [SSS+12]. Since mapping can enhance the

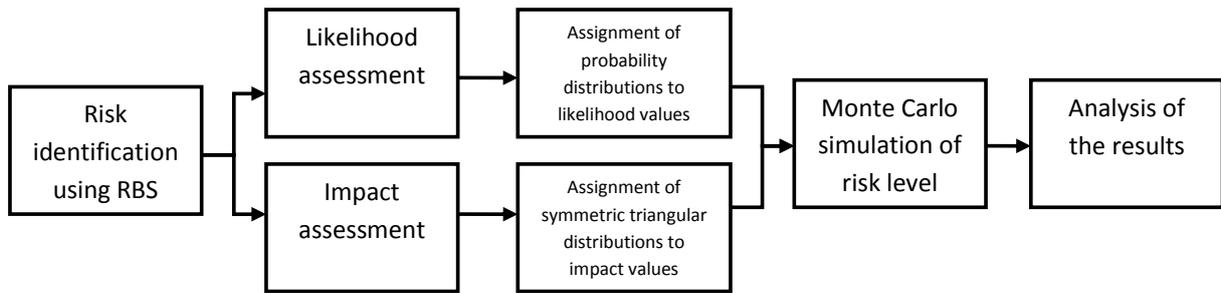


Figure 2. Structure of the proposed method

understanding of risk frequency and appearance (Figure 3), previous research [SSS+12] was found useful during the risk identification process to help team members recognize risks in the product development process. Using the Risk Breakdown Structure risk sources are recognized, but during assessment it is necessary to strictly focus on tasks which were influenced by identified risk sources since valuation of impact is our main concern (as it will be presented later in illustrated example). For that reason, identification of risk source events and risk impact events should be executed in parallel.

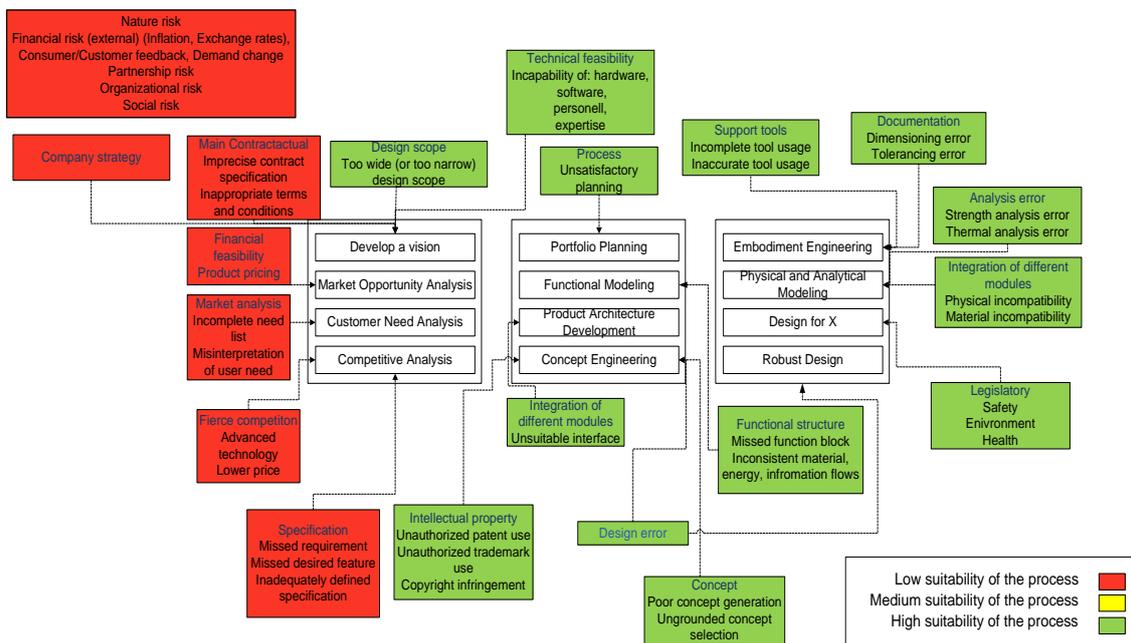


Figure 3. Mapping of risks on sequential product development process

The next step is to analyze recognized and identified risks in terms of their likelihood and impact. The method focuses on a pragmatic approach, therefore only one likelihood and impact per identified risk is considered despite the fact that in literature [SM02] different reasoning can be found.

According to the estimated group consensus decision in verbal form, we defined our triangular distributions for likelihood values based on the above-mentioned previous research (Hillson). From Figure 4, we identified numerical values of selected verbal expression. Skewing of certain values indicates imbalance in pessimism or optimism of interpretation of likelihood expression in the certain risk event (e.g. expression *Likely*).

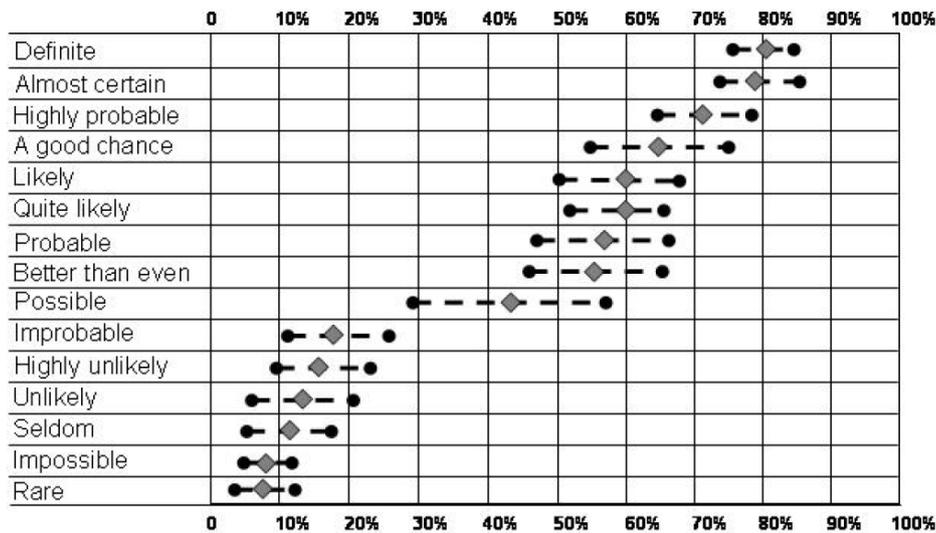


Figure 4. Interpretation of probability-related terms – research results [H04]

During group sessions, experts also value impact in number of working hours or days. After initial estimation of impact, symmetric triangular distributions were assigned to its values. Group session participants determine the value that presents *the most likely impact value* of symmetric triangular distribution. For execution of this part of the estimation phase, a multi-disciplinary team approach is selected to include more opinions. In order to validate the risk analysis results, a feedback session with the group members needs to be performed.

As a result of multiplying these two independent values for any particular risk, a probability distribution of a certain risk level is generated and used for measuring the possible influence on the product development process duration.

Random sampling of risk component values from the input probability distributions is enabled by Monte Carlo simulation. One set of samples represents one iteration, and the resulting outcome from that sample is recorded. Different combinations of uncertain values (“scenarios”) require new calculations to show possible outcomes. Deciding the number of iterations depends on a required quality of achieved distribution of possible outcomes and on the number of input values. A sequence of Monte Carlo analysis steps can be presented as: 1) definition of statistical distributions of input parameters (in this case - triangular), 2) simulation of a model (Figure 5) and 3) analysis of the simulation results (see Example). Using probability functions and Monte Carlo simulation we can avoid fixed single-point estimations and deterministic simulation.

Execution of Monte Carlo simulation of individual risk levels is followed by integration with baseline process duration estimations for the purpose of obtaining duration probability distributions as the final output of the proposed method.

The following section gives an example of the risk assessment approach implementation on a sequential product development process.

4 ILLUSTRATIVE EXAMPLE

In the example, we conducted a risk analysis of an automated car washing facility development process. The client clearly specified the most important product characteristics immediately at the start of the process excluding the necessity for market research. Characterized by narrow iterations and rigid reviews, example represents the sequential product development process. This example type was selected intentionally to focus on justification of the method and accordingly simplicity of the case was our main concern in selecting an appropriate illustrative example.

Using Risk Breakdown Structure for product development and previously defined mappings, risks were identified and mapped on a sequential product development process defined for this specific

product. Figure 5 shows mapping of risk impact events on various product development process phases.

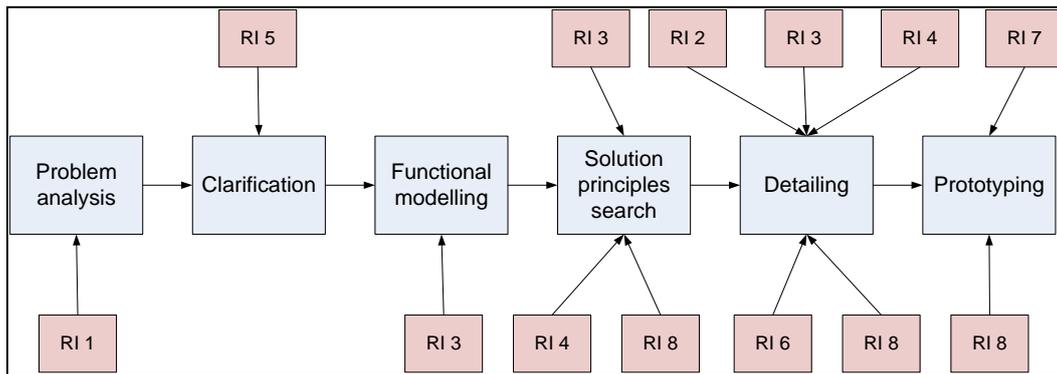


Figure 5. Risk impacts on project level

After the risk identification phase, estimated likelihood and impact values were assigned to each risk, according to the expert opinions (Table 1). Number of random input variables with defined distributions equals the number of identified risks.

Table 1. List of risks with assigned values

	Risk	Verbal description	Probability	Impact	Risk level	Impacted task
1	Unfamiliarity with state of the art	Highly probable	71.3	10	7.13	1
2	Design scope change	Improbable	17.9666667	60	10.78	5
3	Retention of key personnel	Unlikely	13.5333333	20	2.70666667	3
3_1	Retention of key personnel	Unlikely	13.5333333	25	3.38333333	4
3_2	Retention of key personnel	Unlikely	13.5333333	25	3.38333333	5
4	Incomplete design specification (Missed requirement)	Probable	57.1333333	20	11.4266667	4
4_1	Incomplete design specification (Missed requirement)	Probable	57.1333333	50	28.5666667	5
5	Too ambitious requirements	A good chance	64.3666667	5	3.21833333	2
6	Demand change	Seldom	11.6666667	50	5.83333333	5
6_1	Demand change	Seldom	11.6666667	20	2.33333333	4
7	Inadequate funding (Staff, Facilities, External cooperation)	Possible	43.2	30	12.96	6
8	Poor team communication	Rare	8.06666667	5	0.40333333	4
8	Poor team communication	Rare	8.06666667	10	0.80666667	5
8	Poor team communication	Rare	8.06666667	10	0.80666667	6

From our perspective, the model has one main output – duration of the process. Using @RISK developed by Palisade and Microsoft Excel, a triangular probability function was assigned to each risk component value, as explained in the previous sections. Results of the simulation were integrated with original duration estimations of certain product development process phases. After 5000 iterations of Monte Carlo Simulation, the overall time of the product development process was presented as probability function (Figure 6). Plots of PDF (probability density function) and CDF (cumulative density function) show product development process duration distribution after inclusion of risks and their impacts on process phases. Using typical statistics, we can summarize Monte Carlo simulation results with the following figures:

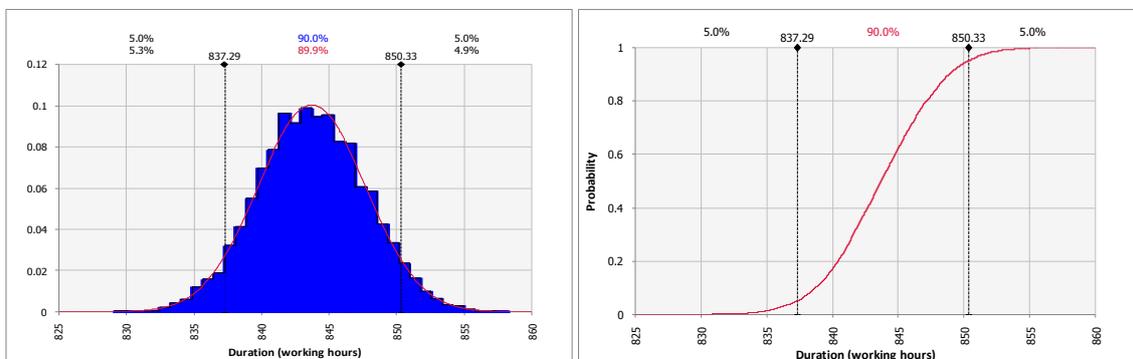


Figure 6. Project duration represented as PDF and CDF

These two representations in Figure 6 show project duration in different ways - according to the probability that certain duration will actually occur. The difference between these two plots arises

from the way they represent information – PDF shows probability with areas, while CDF with distances. Depending on the reference values (e.g. schedule limits) that were set for a given project, acceptability of certain duration can be evaluated as satisfactory or as unsatisfactory.

5 DISCUSSION

Based on the illustrative example, the method presented in this paper could be implemented and used in product development companies, although the method should be tested beforehand in a real environment. This method directs group thinking in incorporating risks in process planning and proposes a way of assessing risks. Using the proposed method, risk management could become a very important part of process planning without exaggerated spending of available time and resources.

The assessment method presented in this paper is based on likelihood and impact estimations which are usually an integral part of risk assessment, but this method also includes an additional quantitative part in the form of Monte Carlo simulations. Likelihood estimations are expressed in interval range (for every verbal expression), since they are more realistic in comparison to “exact” judgements which are very difficult to attain. Assigning symmetric triangular probability distributions to impact single-point estimations, interval ranges are also formed for its values. Pooling and aggregation of individual estimations is solved by group consensus decision in order to avoid additional mathematical manipulations and weighting factors for each estimator. By randomly selecting values from newly formed probability distributions, Monte Carlo simulation provides quantitative results which improve quality of our risk analysis results, but it is crucial to emphasize that they are still based on subjective estimations and therefore their accuracy and precision mustn't be overestimated.

Practical representation of risk likelihood and impact can be a good starting point of risk assessment in a company. Afterwards, the future analysis of risks could be based on historical project data and an established risk repository, but its rigour and level of granularity will depend on the complexity and importance of a certain project. For smaller projects, devoting too much energy to risk management may detract attention away from achieving project objectives and for that reason practicality and usability should be the most important characteristics of risk management.

Since the risk management process is, in its nature, also iterative, there should always be an option to add or subtract some risks from the list. During the product development process, some new risks will appear and maybe some of the previously identified risks will be mitigated, and according to these changes our risk assessment results can be modified. Therefore, monitoring should be tightly linked with the assessment phase to recognize variations in likelihood and impact estimations. Appropriate mitigation of risk can affect the value of risk likelihood and impact and consequently risk assessment actions need to be executed repeatedly during the process. Moreover, conducting more risk sessions will encourage participants to discover refinements and improvements within a risk analysis process but also gaining more experience and knowledge about the process would allow more precise risk component estimations. Increasing the maturity of risk management capabilities within organization, more employees on different organization levels will be included in the risk sessions.

Considering the literature review and illustrative example, in order to enable comprehensive risk assessment of the product development process, it is crucial to enable switching between different RBS and process decomposition levels. Although we focused on the project level, mapping risks is also possible on lower levels of process decomposition. The same process of risk assessment can be executed on strategic, project and operational levels and specific risks can now be shrunk to tolerable levels regardless of process level (although in this paper we didn't discuss mitigation strategies). Of course, risk impact on various process levels does not have the same influence on overall process and this needs to be taken into account. In order to shorten the required time of risk estimation, focus can be put on specific tasks or work packages which were previously defined (e.g. lessons learned) as “risky”.

Although the research has reached its aims, it was still subject to a few limitations. Since the majority of literature in risk management and likelihood is in English language, the same terms were used in our approach. These terms should be translated on other languages to ease understanding and usage of certain equivalent terms in various countries.

Furthermore, one of the limitations of this approach is modeling risks as independent events due to practicality. Relations between different risk events exist and they should be considered in future research. The illustrative example is suitable for representation of this approach, but a more complex one would also require more demanding process modeling, introducing the need for formal simulation process models.

6 CONCLUSION

In order to mitigate estimation bias and subjectivity of selected estimators, the approach proposed in this paper is based on a combination of qualitative and quantitative risk assessment methods. Using classical estimation methods and upgrading their output with triangular probability distributions and Monte Carlo simulation provides more reliable results. The final outputs of this method are PDF and CDF plots which represent distributions of the duration of product development process and can provide valuable insight and information during process planning and monitoring phase. Using proposed method, risk levels of various independent risk events can be assessed and integrated with the previously estimated duration of a product development process.

To further improve this approach, interactions and relations between different risks need to be included to comprehend the full complexity of risks in product development process. Perceiving risks as dependent events could considerably extend the scope of this approach, but in that case it would also require more demanding process modeling. Furthermore, one of the possible research directions is to extend the approach to resources, performance etc.

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