# A Two-phased Risk Management Framework Targeting SMEs Project Portfolios

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Keywords: Project Planning, Risk Analysis, Monte-Carlo Simulation, Analytic Hierarchy Process, Risk Minimisation, Toolset, Case Study.

Abstract: Managing project risks is challenging for many enterprises, especially smaller ones, because they generally only have very limited method or tool support, i.e. basic, qualitative and rather short term reaction to the occurrence of risks. This results in higher vulnerability and reduced competitiveness. This paper proposes a risk management framework fitting SMEs needs by providing a way to adequately quantify risks and address them at two levels. First, an Analytical Hierarchy Process (AHP) is used to perform cost-benefit analyses of the possible mitigation actions assessed through Monte-Carlo simulations. Second, an on-line optimisation tool is used to make sure the planning is following the minimal risk path and reschedule mitigation action as soon as a risk has materialised. To address the limited SMEs resources, the core components are provided as Open Source with a clean application programming interface for easing integration with existing tools. A reference integration with the Open Source Redmine project management tool is also provided.



## 1 INTRODUCTION

Small and medium-sized enterprises (SMEs) are driving the economy worldwide, e.g. in Europe they ensure about 66 % of the jobs and generate almost 60 % of the wealth (Muller et al., 2015). Companies are project-driven, each project being a “temporary endeavour undertaken to create a unique product, service, or result” (PMI, 2008). Projects have to face many risks that can cause failures, delays or budget overruns. Such risks are not restricted to SMEs, but they can be very harmful or even fatal for SMEs due to their limited size, maturity, resources, lower adherence to standards, despite a larger flexibility (Ghobadian and Gallear, 1997).

Standards or frameworks for project management like PRINCE2(Murray, 2009), PMBOK (PMI, 2008) and ISO31000 (ISO, 2009) are available to correctly address project risks. However, in SMEs these are rarely used due to their complexity and lack of flexibility. Also, SMEs are often not even aware of the standards’ and frameworks’ existence. In reaction, more specific approaches for SMEs have been defined and validated: a risk driven methodology was developed by (Marcelino-Sádaba et al., 2014) including simple tools, templates and risk check-lists of including actions and indicators. In the Netherlands, Situation Project Management Methodology (SPMM) which enables to tune the project management methodology to the context was experimented with SMEs (Heupers, 2011). Several lightweight standards have been defined such as the ISO29110 in the IT sector which is free and comes with useful deployment toolboxes (ISO, 2011). However large scale surveys reveal that currently available methods for SMEs mainly focus on the early phases (risk identification/analysis) and provide incomplete coverage of the risk mitigation step (Verbano and Venturini, 2013).

This paper summarises the main achievements of the PRIMa-Q project to address the above mentioned

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Ponsard, C., Germeau, F., Ospina, G., Bitter, J., Mende, H., Vossen, R. and Schmitt, R.
A Two-phased Risk Management Framework Targeting SMEs Project Portfolios.
DOI: 10.5220/0008119704060413
In *Proceedings of the 9th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2019)*, pages 406-413
ISBN: 978-989-758-381-0

shortcomings in project risk management (CORNET, 2016; Ponsard et al., 2017). As part of the CORNET program, PRIMa-Q is focusing on methods and tools for SMEs. The main project goal is to enable a minimal form of quantitative reasoning and also to be able to address complex contexts such as multi-project portfolios, shared resources, and presence of uncertainties. Important non-functional requirements for SMEs like usability, learnability and ease of integration are also considered. Finally, cost of ownership is also addressed by providing the resulting software in Open Source with both an application programming interface (API) and a reference implementation based on the Redmine tool (Lang, 2006).

Our proposed approach actually relies on different methods and techniques that have demonstrated their capability to address risks while hiding the implementation complexity behind a few simple concepts. Our focus is the risk mitigation phase, so we assume that basic project management and risk identification support are available (as fall-back such functionalities are present in our reference implementation). Our approach is considering two levels of risk management:

1. Quantified guidance to help in selecting the best mitigation action(s). Such actions are captured in a knowledge base of measures. Their impact on a specific (set of) running project(s) is assessed using a cost-benefit model using an Analytic Hierarchy Process (AHP) for decision making (Saaty, 2000; Saaty, 2008). In order to quantitatively assess the effect of each action, a Monte-Carlo simulation method is used (Zio, 2013) based on our past experience (Landtsheer et al., 2016).
2. Guidance is also provided in the planning phase. We consider here project tasks, resources and dependencies but also the effect of risk mitigation action on planning like providing time buffer for some risky tasks, increasing the availability of specific highly demanded/scarce profiles/equipment. The provided support is relying on online optimisation techniques based on an efficient constraint-based local search (OscaR, 2012; Ponsard et al., 2019), which means it will constantly adapt to manually added decisions or to external factors like the materialisation of expected or unexpected risks.

This paper is structured as follows. Section 2 explains our method using a detailed workflow. Then Section 3 presents the architecture of the developed tooling. Section 4 performs a validation and discussion on a project derived from a real case. Finally, Section 5 concludes and presents our future work.

## 2 PROPOSED APPROACH

This section first gives a general overview of the workflow before more detailed descriptions follow.

### 2.1 Workflow

The proposed risk management workflow is depicted in Figure 1. It is divided into three main parts grouping specific components developed by the collaborating parties: the scheduling engine (including database), the quantification framework and cost-benefit modelling. Furthermore, the interface is divided into three parts. Steps 1 to 6 represent the risk simulation. Steps 7 to 9 stand for the simulation of measures counteracting risks. Step 10 to 12 rep-

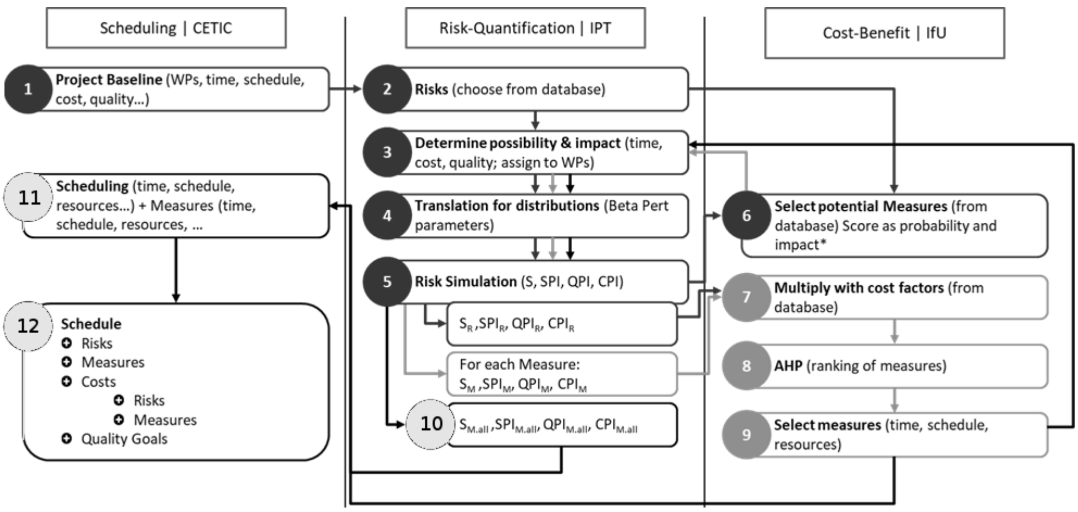



Figure 1: Quantified risk management workflow.

resents the subsequent scheduling including the selected measure(s).

The workflow can be described as follows. First (1), the project is described through its time, planning, costs, quality and work packages. This information is captured using existing tools or through the forms of our reference implementation.

Based on this information, possible risks that may occur are identified in (2). These risks can either be taken from the existing database or added individually. In (3), the possible effects of the identified risks on e.g. time, cost and quality are determined. As a first step for the following simulation, the deterministic effects are translated into a specific parametric probability distribution in (4). These parameters form the basis of the following Monte-Carlo simulation.

This Monte-Carlo simulation takes place in (5). There, success indexes are computed. Those are detailed later but reflect the classical project triangle about time/cost/quality. On the basis of the selected risk, possible measures that act against this risk are identified in (6). These can also be taken from the ready-made database. The blue arrow that connects (6) to (3) makes it clear that the cycle described above is now starting again. First, the possible effects of the measures are determined and then translated into β-PERT parameters. Subsequently, a Monte-Carlo simulation is carried out again for each individual measure to provide estimated of all success indices.

These values are multiplied by the cost factors from the database in (7). In the subsequent AHP, these weighted values are evaluated and ranked in (8). This ranking indicates which of the measures should best be implemented taking into account the factors of cost, time and quality. In (9), one or multiple risk treating action(s) is/are selected based on the cost-benefit model for the specific risk and project. This process is detailed later in this section and forms the first level of our guidance.

The selected action(s) are implemented inside the project. The combination of risks and selected measure(s) runs through the simulation again, as indicated by the black arrow connecting (9) and (3). The resulting values of the success indexes (10) are then used for the planning phase (11). During this phase, residual risks are also considered using scheduling techniques. Those last steps compose the second level of our guidance and are detailed later in this section.

## 2.2 Step 1: Modelling Project and Risk

A mandatory step for any structured and quantitative approach to reason on project and risk is to have a clear model of those concepts. For this purpose we developed a joint meta-model already sketched in (Ponsard et al., 2019) and which is refined here. It is composed of two overlapping views.

The project view is depicted in Figure 2 and has two main concepts: *Step* and *Resource*. A step is an abstraction of a whole project or phase or task depending the required level(s) of granularity and multiple levels are also supported. Each step has several information such as due date, planned effort. In addition to refinement. *Steps* can also have other relations like the classical precedence. They also require one or many *Resources* characterised by their *Capabilities*. A *Resource* can be a *Physical Resource* or a *Stakeholder*.

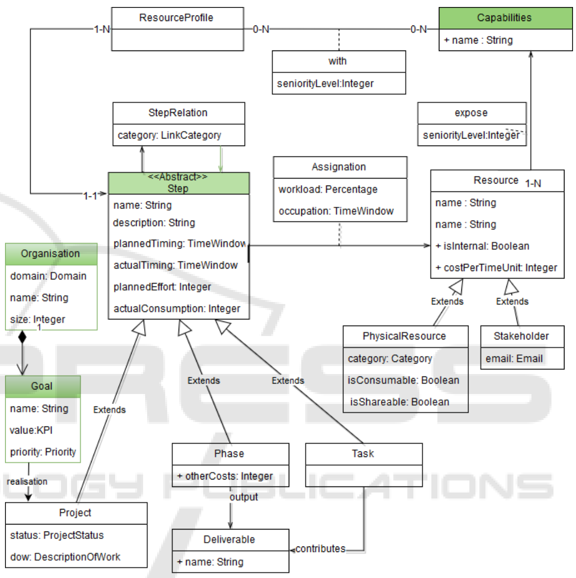



Figure 2: Project part of the meta-model.

Figure 3 shows the risk part. A *risk* obstructs a *Goal* and has some *Impact* with some likelihood. The *Impact* can be mitigated by some *Action* to by applied at a specific *Step* and which will restore some *Goal*. A classification of *Constraints* related to cost/quality/delay issues is available and are directly related with some *Impacts*. This will help to guide the selection of mitigation *Actions*.

The meta-model is instantiated inside a knowledge base which is populated with different risks and measures. The following classification has been established based on a literature review and validation with a set of companies involved in the project:

- Scope Risks: new requirements, strategic change.
- Scheduling Risks: duration, dependencies.
- Resource Risks: capability and availability.
- Technology Risks: related to hardware and software availability, reliability, security issues.

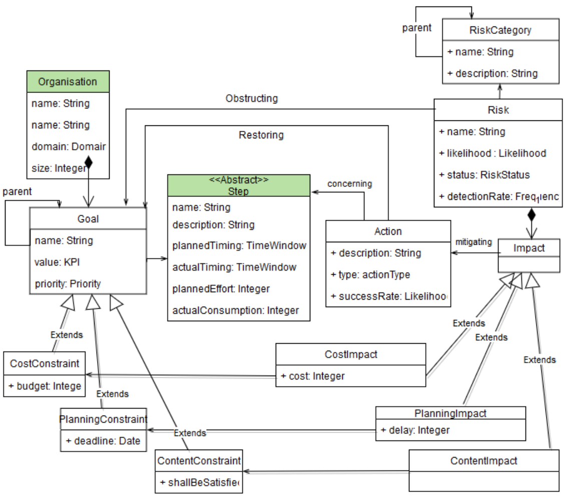



Figure 3: Risk part of the meta-model.

- Environment risks, e.g. government, market, etc.
- Management risks, e.g. organisation complexity, available skills, bureaucracy.

## 2.3 Steps 2-5: Quantification and Simulation of Risks

Another preliminary to achieve our objective of risk mitigation is to adequately quantify project risks. Our quantification approach is based on a few Key Performance Indicators for the project success. These indicators are successful if greater or equal to one. The closer to zero, the larger the failure.

- *Schedule Performance Index* (SPI) targets the time dimension, i.e. how close the actual (total) time is compared to the planned (total) time from the Schedule-Cost Baseline. The actual time is modelled as a random variable resulting from the sum of the time duration for individual project steps on the critical path. The SPI is computed as the ratio planned vs actual time.
- *Cost Performance Index* (CPI) follows a similar approach, i.e. by comparing the planned (total) costs of the cost baseline with the actual costs. It is also modelled as a random variable. The total costs include all costs and are independent of the critical path. The CPI is computed as the project budget divided by the actual costs.
- *Quality Performance Index* (QPI) is more sophisticated. It is regarded as a combination of all objectives which do not represent explicit budget or deadline targets in order to provide a holistic view of risks. It is composed of basic, performance and enthusiasm characteristics which can also directly be related to different goals of the organisation. Satisfaction metrics are used to quantify and aggregate those dimensions resulting on a scale from 0 (complete failure) to 1 (total success) in all dimensions.

Those indicators can be measured on actual projects but also estimated on model simulations. Most parameters are of stochastic nature (task duration, resource availability, quality of a result) and are modelled using probabilistic distributions. Such distributions are a way to quantify risks partly and involve some subjectivity in the choice. To keep the model simple, we rely on the parametric modified β-PERT distribution depicted in Figure 4. It uses an intuitive three-point estimation of continuous variables and as proven very useful to capture expert opinions (Vose, 2008). In addition, the Bernoulli distribution is used to model discrete variables.

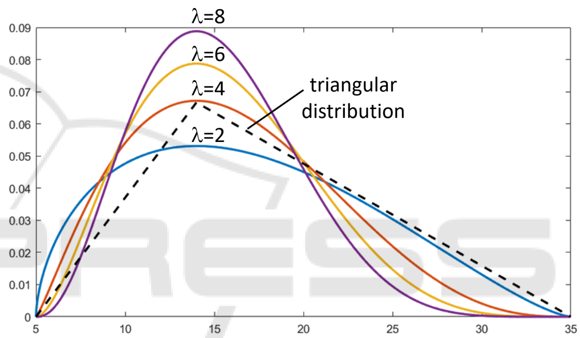



Figure 4: Modified *beta*-PERT distribution.

Using the Monte-Carlo technique, a large number of discrete event simulations can be computed to estimate the probability distribution of the above indicators and to quantify the risk of failure given some acceptable threshold, e.g. in 95% of the case, we will be on-time. Figure 5 shows the computed distributions for *SPI*, *CPI* and *QPI*, with a lower resolution for the latter. The values corresponding to the target probability threshold are also depicted.

Note that computing the global success requires carefulness given some dimension might not be independent. To cope with this, the Sobol index is used in addition of the above indexes. The Sobol index expresses the possible variance reduction of the overall result if an input variable is assumed to be safe. A variance reduction means that the possible results of a target expression can be narrowed down, i.e. the target expression has a lower risk in the sense of reduced variability. Consequently the Sobol index is an appropriate measure for assessing the impact of individual risks. The global success $S$ aggregates the result of each simulated project using formula 1.

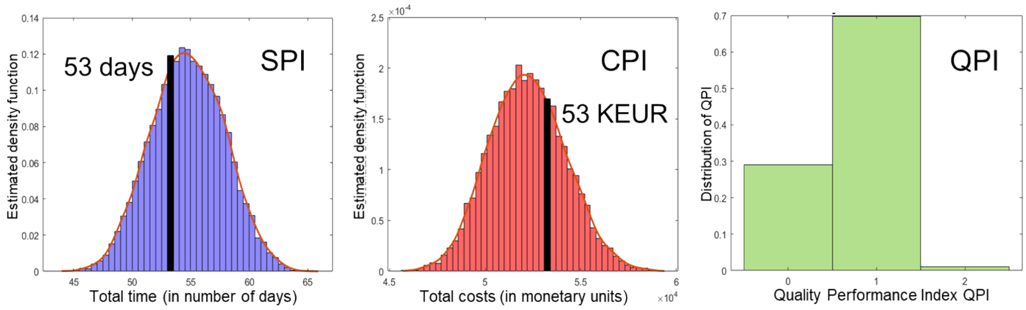


Figure 5: Distributions resulting from the Monte-Carlo simulations.

$$S = \frac{\#\text{ successful project}}{\#\text{ projects}} \quad (1)$$

## 2.4 Steps 6-9: Mitigation Action Selection

Our approach is to contrast the benefits of reduced/mitigated/eliminated project risks with the costs of conducting specific risk-treating measures. It is based on an AHP, a multi-criteria-decision-analysis (MCDA) technique. It facilitates a structured comparison, ranking and thus decision regarding measures, based on multiple criteria which are S, SPI, CPI and QPI in our case.

In order to improve usability and allow for qualitative expert inputs, each cost factor is based on two dimensions: quantity of costs and complexity of implementation, which can each be divided into discrete sets: e.g. low, middle and high. Each combination of values for the dimensions is accompanied by a numerical cost factor, that allows further processing. The resulting cost factor matrix is shown in Figure 6.

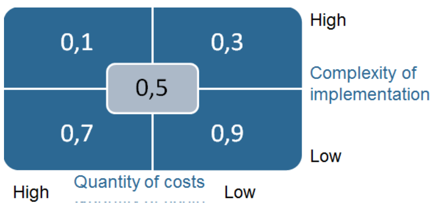


Figure 6: Cost factor matrix.

The AHP pre-processing is as follows:

- Step 6 - the primary input is a list of potential risks and potential treating measures. For each measure, the database contains the probability of success, quantity of impact, effect on risk probability and on risk impact as well as the cost factors.
- Output of Step 5 - those inputs refined into our S, SPI, CPI and QPI indexes using the quantification approach presented in the previous section.
- Step 7 - indexes are multiplied by the cost factor resulting in $P_S$, $P_{SPI}$, $P_{CPI}$ and $P_{QPI}$ parameters which are the real inputs for the AHP.

A default additional measure "No action" with no effect and cost factor 1 is also always considered.

Within the AHP approach (step 8), the potential measures are pairwise compared for each parameter $P_S$, $P_{SPI}$, $P_{CPI}$ and $P_{QPI}$. Therefore, the distance between the parameter values of two measures is calculated and normalized on a scale between 1 and 9 using the equations detailed in Figure 7 (Saaty, 2000).

$$A_{S,R1} = \begin{bmatrix} a_{1,1} & \cdots & a_{1,k} \\ \vdots & \ddots & \vdots \\ a_{n,1} & \cdots & a_{n,k} \end{bmatrix} \; with\; n,k \in M_{j,R1}\; and$$

$$a_{n,k} = \begin{cases} (P_{S,Mj-1,R1} - P_{S,Mj,R1}) * 8 + 1, & for\; P_{S,Mj-1,R1} \geq P_{S,Mj,R1} \\ \left((P_{S,Mj,R1} - P_{S,M-j,R1}) * 8 + 1\right)^{-1}, & for\; P_{S,Mj-1,R1} < P_{S,Mj,R1} \\ 1 & for\; n = k \end{cases}$$

Figure 7: AHP pairwise comparison computation.

This leads to four n x n matrices (for $P_S$, $P_{SPI}$, $P_{CPI}$ and $P_{QPI}$). Computation of their Eigenvectors produce a percentage-based ranking of measures for each parameter. The rankings of each index must then be combined. Within the project, all parameters were assigned the same weight. However, different weights could be used to stress more on specific dimensions. The final result (step 9) is a global ranking of measures from the most effective to the least effective.

## 2.5 Steps 10-12: Risk-aware Scheduling

The selected actions are applied to the model and a final simulation is run to retrieve the actual risk parameters (step 10). The resulting schedule can then be computed (step 11). This step can also address risks that were not fully solved by the previous AHP process because scheduling risks are only covered by a restricted subcategory of the risk database. More specific heuristics are applied here to address schedule impacting risks such as:

- Tasks with poor estimation of scope or feasibility.
- Tasks potentially impacting many dependent tasks.
- Tasks involving many resources or unreliable or scarce resources.
- Complex portfolios with several parallel projects.

Examples of heuristics have been investigated using efficient optimisation tools like (OscaR, 2012) and (Smet, 2006) and are reported in (Ponsard et al., 2019).

## 3 TOOL IMPLEMENTATION

The global architecture of our tooling is shown in Figure 8. It is composed of:

- The PRIMa-Q core engine containing a relational database reflecting our conceptual model and a related web-based interface for easing the connection with existing platforms, e.g. JIRA or Trello. Specific adaptors can be developed to synchronise project and/or risk data. The core engine also includes a scheduling capability based on the Oscar optimisation library (OscaR, 2012).
- A reference implementation based on the Redmine platform (Lang, 2006). It illustrates an integration scenario with the back-end repository and a specific front-end plugin to provide a full user interface for driving the risk management process and presenting the resulting schedule.
- The AHP (Excel-based) cost-benefit tool (Goepel, 2013) relying on Monte-Carlo engine (Matlab-based). Both can access their data through the web-service API.

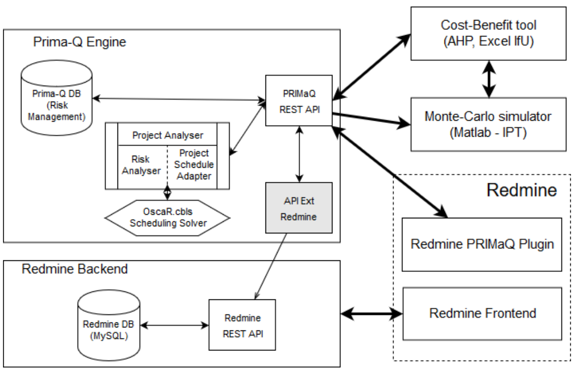



Figure 8: Tool architecture.

The implementation is easy to deploy on a server or a local virtual machine running Linux. An online demonstration is accessible from the following URL: http:\\prima-q.cetic.be.

## 4 VALIDATION CASE STUDY

### 4.1 Description

Our case is a R&D project spanning over two years and composed of five main work packages each typically composed of three to five tasks. The project involved about ten researchers (not simultaneously) from three organisations located in two countries.

Although the project was designed to be run in an agile mode, a number of dependencies were identified such as the requirements backlog (WP1) must be finished before starting the design (WP2) and continuous validation (WP5). Ending specific WP2 tasks is also mandatory for starting some WP4 implementation tasks.

Resources were only specified as overall effort per task and partner. The actual allocation needs to be done on the basis of available people with a profile matching the task needs (e.g. an analyst for the requirements or a developer for the software coding).

Typical risks to be addressed are:

- A few key experts simultaneously required on multiple projects resulting in delays.
- Poor estimation of real task duration due to technological risk or integration issues.
- Validation delayed due to external causes like poor user involvement.

### 4.2 Capturing Project and Risk Data

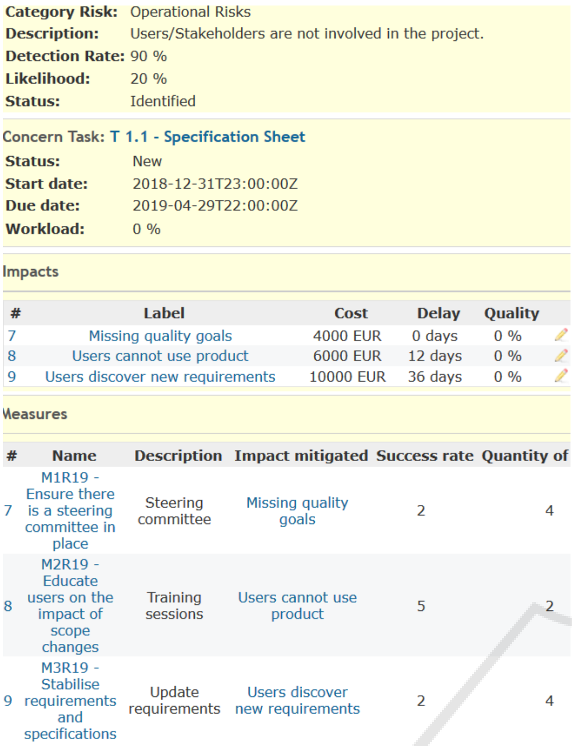
The provided implementation contains a complete set of forms (about 20) to create/read/update/delete information related to projects and risks. Figure 9 shows a key screen where a risk can be linked to a task.

Risks of project Demo Project New

| # | Concern Task | Risk | Likelihood | Status | | |
|---|---|---|---|---|---|---|
| 1 | T 1.1 - Specification Sheet | R19 - Failure to gain user involvement | 20 % | Identified | Edit | Destroy |
| 2 | T 3.2 - Deployment activites | R19 - Failure to gain user involvement | 20 % | Identified | Edit | Destroy |
| 7 | T 3.3 - Evaluation | R8 - Schedule too short | 80 % | Identified | Edit | Destroy |
| 8 | T 3.2 - Deployment activites | R11 - Inappropriate budget | 50 % | Identified | Edit | Destroy |
| 7 | T 3.3 - Evaluation | R8 - Schedule too short | 80 % | Identified | Edit | Destroy |
| 8 | T 3.2 - Deployment activites | R11 - Inappropriate budget | 50 % | Identified | Edit | Destroy |

Figure 9: Form to associate risks to project tasks.

Figure 10 details a specific risk related to the failure to gain user involvement. Different impacts are estimated about quality, usability or delay resulting from missing requirement. Based on them, a number of measures are specified such as education, steering committee involvement or gathering requirements using other channels. Estimates about effectiveness of each measure are also captured.



| | |
|---|---|
| **Category Risk:** | Operational Risks |
| **Description:** | Users/Stakeholders are not involved in the project. |
| **Detection Rate:** | 90 % |
| **Likelihood:** | 20 % |
| **Status:** | Identified |

Concern Task: T 1.1 - Specification Sheet

| | |
|---|---|
| **Status:** | New |
| **Start date:** | 2018-12-31T23:00:00Z |
| **Due date:** | 2019-04-29T22:00:00Z |
| **Workload:** | 0 % |

Impacts

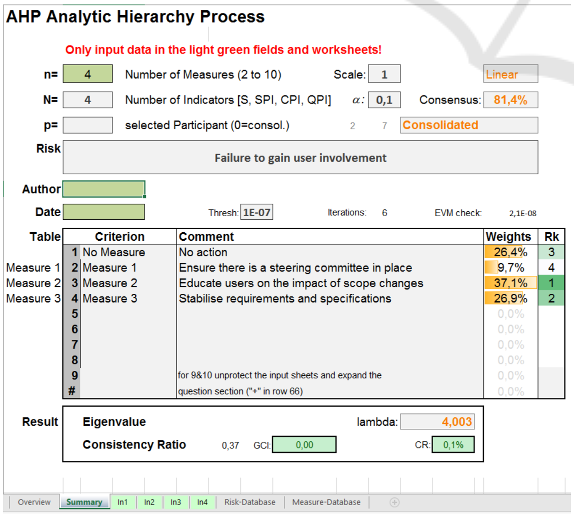
| # | Label | Cost | Delay | Quality |
|---|---|---|---|---|
| 7 | Missing quality goals | 4000 EUR | 0 days | 0 % |
| 8 | Users cannot use product | 6000 EUR | 12 days | 0 % |
| 9 | Users discover new requirements | 10000 EUR | 36 days | 0 % |

Measures

| # | Name | Description | Impact mitigated | Success rate | Quantity of |
|---|---|---|---|---|---|
| 7 | M1R19 - Ensure there is a steering committee in place | Steering committee | Missing quality goals | 2 | 4 |
| 8 | M2R19 - Educate users on the impact of scope changes | Training sessions | Users cannot use product | 5 | 2 |
| 9 | M3R19 - Stabilise requirements and specifications | Update requirements | Users discover new requirements | 2 | 4 |

Figure 10: Form to identify risks impacts and measures.

Figure 11 shows that the AHP recommends action 2 about education over requirements improvement and no action. Those rank almost the same while enabling the steering committee is less effective.



AHP Analytic Hierarchy Process

Only input data in the light green fields and worksheets!

n= 4 Number of Measures (2 to 10) Scale: 1 Linear

N= 4 Number of Indicators [S, SPI, CPI, QPI] α: 0,1 Consensus: 81,4%

p= selected Participant (0=consol.) 2 7 Consolidated

Risk: Failure to gain user involvement

Author

Date Thresh: 1E-07 Iterations: 6 EVM check: 2,1E-08

| Table | | Criterion | Comment | Weights | Rk |
|---|---|---|---|---|---|
| | 1 | No Measure | No action | 26,4% | 3 |
| Measure 1 | 2 | Measure 1 | Ensure there is a steering committee in place | 9,7% | 4 |
| Measure 2 | 3 | Measure 2 | Educate users on the impact of scope changes | 37,1% | 1 |
| Measure 3 | 4 | Measure 3 | Stabilise requirements and specifications | 26,9% | 2 |
| | 5 | | | 0,0% | |
| | 6 | | | 0,0% | |
| | 7 | | | 0,0% | |
| | 8 | | | 0,0% | |
| | 9 | | for 9&10 unprotect the input sheets and expand the | 0,0% | |
| | # | | question section ("+" in row 66) | 0,0% | |

Result: Eigenvalue lambda: 4,003

Consistency Ratio 0,37 GCI 0,00 CR 0,1%

Overview | Summary | In1 | In2 | In3 | In4 | Risk-Database | Measure-Database

Figure 11: AHP pairwise comparison computation.

Figure 12 represents the initial and final Gantt produced by our scheduling tool. It shows the main dependencies and we can see T2.1 is planned after the end of T1.1 due to such a dependency.

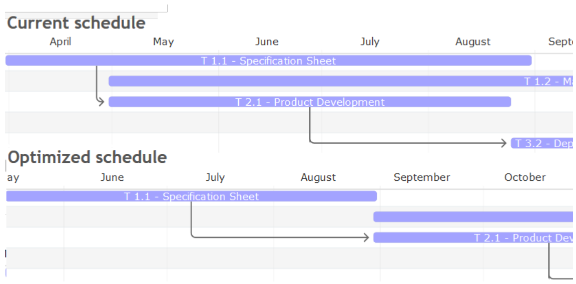



Figure 12: Initial and optimised Gantt.

Note that T1.2 is also postponed until the end of T1.1 but in this case due to a resource issue on a common resource (j.bitter) which is a bottleneck here. This is also visible in Figure 13 as the resource is allocated 60 % then 50 % which rules out a parallel allocation because it would result in 110 % load.

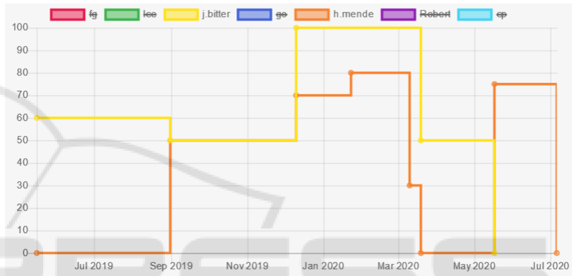



Figure 13: Resource load.

## 4.3 Performance Assessment

The global performance of the involved tools is as follows:

- The Monte-Carlo simulation requires N+1 simulation of risks: one for each measure and a final one for the selected set of measures. In order to produce a precise approximation of the probability distributions, enough simulations must be run, around 1000 in practice. This results in computation times of about a few seconds on a laptop (single core of an I7 Intel CPU). The whole process takes under a minute.
- The selection of measures involves some tricky matrix computation. The current Excel implementation is able to solve it within seconds on the same configuration.
- The final planning generation step used the OscaR.CBLS local search solver. There is no guarantee to find the optimum but the stop criteria can be configured to reach a good balance between search time and quality. In practice, near optimal schedules can be produced in about 20 seconds for moderately complex projects (i.e. about 30 tasks)

and using a virtual machine with a computation power similar to the above end-user configuration.

Globally the whole process is compatible with an interactive use of the tooling and allows the user to wait for answers, analyse results, perform manual adaptations like reassessing some impacts, introducing additional mitigation actions, changing some tasks, adding resources, etc. After this a new risk analysis process take place until the user is confident the risks are adequately mitigated.

## 5 CONCLUSIONS AND NEXT STEPS

This short paper has reported about our work to provide a tool-supported methodology for helping SMEs to move towards a more quantitative approach for risk management. Our approach provides a modelling reference, risk classification, tooling for measure selection and for the planning phase. The whole framework is provided as Open Source with a SaaS reference implementation available online. Our validation so far is still limited but we could involved a handful of end-user manufacturing companies and software editors which helped to improve usability and to ease the integration.

Our future work aims at providing integrated services within our core platform for computing the AHP and Monte-Carlo simulations. We also plan to start collecting more data to enable some form of learning of risks to enrich the available knowledge base and increase the risk coverage. Specific cases are being discussed and relates to enterprise architecture, agile project management and project requirements engineering.

## ACKNOWLEDGEMENTS

This project was partly funded by the Belgian Walloon ePick (7570) and PRIMa-Q (1610088) projects. On the German side PRiMa-Q (IGF-No. 183 EN) was funded by the AiF within the framework of the program for the promotion of industrial joint research and development (IGF) of the Federal Ministry of Economic Affairs and Energy on the basis of a resolution of the German Bundestag. We also thank our user committees for their collaboration and feedback.

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