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Survive IT! Survival analysis of IT project planning approaches

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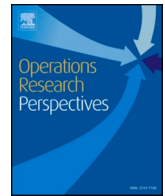
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Survive IT! Survival analysis of IT project planning approaches

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ABSTRACT

Despite the emerging importance of IT projects and the application of new flexible project management approaches, such as agile and hybrid methodologies, there are still many unsuccessful projects. Therefore, it is important to study which risk factors have the highest influence on the success and survivability of IT projects, how they are related to each other, and which project planning and management approaches can mitigate project risk the most. The goal of the study is twofold. On the one hand, a new risk analysis tool is proposed that handles the project flexibility and the dependency of the risk factors at the same time. On the other hand, with the proposed risk analysis tool, the effects of project management approaches for scheduling performance and risk mitigation are analyzed. With the proposed risk management tool, we determined the level of flexibility that allows flexible project management methods to gain advantage over traditional methods. In addition, we answer whether it makes sense to apply flexible planning for non-IT projects.

1. Introduction

Although traditional project planning methods used in construction projects are still being applied to software development projects (SDPs), more flexible methods, such as agile and hybrid project management, have taken the lead in project planning and management [15,70] since the beginning of this decade. Although the combination of traditional and agile approaches has already been specified in the literature [see, e.g., 59], these hybrid approaches are suffering from several challenges in the phases of project management from planning to tracking [57,59]. The differences in perception between the two approaches are further deepened by the fact that agile and hybrid project management use different words for the same or very similar terms used in traditional project management [12]. While the methodological support for traditional project planning techniques is quite broad [see an excellent review in 10], several practical but much less algorithmic methods have been developed for planning and scheduling (in the agile world: backlog management in the cadence) for agile and hybrid projects. In addition, while few scheduling methods, such as [29,37], support agile and hybrid project scheduling [see, e.g., 38], to our best knowledge, there is no known quantitative risk evaluation tool to extend agile and hybrid project planning. Although there is an inherent and implicit risk

mitigation in agile methods [47], these methods preclude assessing and quantifying the effects of the choices or outside risk factors on the project performance. This paper seeks to fill this gap. We use the term *project risk* to convey a negative effect (e.g., delays, cost overruns) multiplied by the probability of occurrence. In project management, risk information is crucial for evaluating performance changes beyond the actual project status. While the success of agile and traditional project management approaches is regularly compared by the SGI [56], the hybrid approaches have not yet been investigated from risk management aspects. At the same time, the knowledge of important risk factors can be crucial for tracking and managing flexible project plans. In this study, traditional [16], agile [37], and hybrid [38] project scheduling methods are implemented as software applications, hereafter project management agents (PMAs). Every agent must handle the issues that arise in changing task demands and scope creep. While the authors refrain from claiming that the proposed risk management system can account for all emerging risks, it does, however, provide an opportunity to address the risks and their interrelationships.

Risk management tools and techniques have been developed to improve project success; however, similar to project planning tools, their support for flexible project planning approaches is limited. Many project risk management tools evaluate the risk characteristics

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independently and focus on the analysis of individual risks [see, e.g., 4, 13]; however, recent papers propose project risk models that consider the interdependencies of the risk factors [see, e.g., 28, 69]. Not only correlation but also causality among the risk factors can usually be observed [5,53]. In the proposed model, both correlation and causality based on conditional probability can be modeled among risk factors. Moreover, Wang et al. [67] considered risks as deviations in project objectives regarding duration, cost, quality, influence on the environment and safety (health). The authors investigated the relation of project objectives, risk factors and risk effects in a so-called meta-network. This approach already handles the stratification and interdependencies of risk factors for a project; the main challenge is to specify meta-networks for all kinds of projects. However, to date, this approach has regrettably only been used in traditional project management, such as construction projects [67], and neglects the impact of changing customer requirements that affect the project structure and task priorities. In contrast, risks in IT projects cannot be considered independent. Therefore, a simulation tool for IT projects is required to handle both the flexible nature of projects and interrelations among risks. Such a tool can serve as an essential part of a project decision support system that helps management choose the most adequate approach for an IT project.

Instead of focusing on one or several projects, we treat a large set of projects from project databases. In our models – similar to the meta-networks – risk factors and risk effects as well as project objectives and stakeholders can be connected to each other. Furthermore, to compare and analyze how a project planning approach (implemented by a PMA) can mitigate project risks, a random forest-based survival (RFS) analysis [34] is also applied. In contrast to the traditional regression-based survival analysis, the RFS is more robust. It handles the interdependencies among the risk factors [72,1].

The RFS approach offers adequate tools to model the sequence of risk factors and analyze the importance of the stratification of risks; nevertheless, these methods are hardly applied in project risk management. Against this backdrop, the virtual neglect of survival analysis in project risk management defies understanding, particularly given that newer RFS models are very robust [see, e.g. 34, 60]. Recent RFS methods even handle the interdependency between factors [9], and we show that stratification of risk effects can also be analyzed by an adaptation of the discrete-time version of RFS [see these methods, e.g., 8, 45].

In this study, the following research questions (RQs) are stated.

- RQ_1 Which project planning and scheduling approaches allow the most projects to survive the changes in task demands and customer requirements?
- RQ_2 For the survived (i.e., still feasible) projects, which project planning and scheduling approaches mitigate most of the effects of project risk?
- RQ_3 What is the importance of the risk factors to the sensitivity of project schedules?

This study proposes a survival analysis-based risk evaluation (SABRE) tool to compare project management approaches. This tool can handle the interdependence between risk factors, and while supporting flexible planning and management approaches, new risk factors, such as changes in customer requirements and preferences and changes in project logic structures, can also be treated. The proposed tool is tested by considering standard project databases. The task demands and constraints of the structure of the projects are changed via Monte Carlo simulation (MCS).

By the proposed SABRE tool, traditional, agile and hybrid project management approaches are also modeled and compared in order to explore which method can mitigate most of the effects of project risks. Based on a considerable number of project plans from several project databases, the importance of risk factors is also reviewed.

The rest of this paper is organized as follows. Section 2 provides a brief review of project planning approaches, project risk management

and mitigation techniques and their shortcomings. In Section 3, the proposed new risk simulation framework, the SABRE tool, is presented. Section 4 presents how the project planning approaches are compared with survival analysis based on simulation and real project databases. Finally, in Section 5, we draw conclusions, and in Section 6, we specify the limitations of our research and present suggestions for future research.

2. Related works

In Section 2.1, first, the applied terms and definition for project feasibility and project success are stated. Subsequently, Section 2.2 describes the software project risk approaches, and in Section 2.3, the applied meta-network structure is presented, which is the first application for software project risk management. In Section 2.4, the project management approaches and their agent-based implementations are shown and demonstrated in an example. Finally, in Section 2.5, the applied simulation tool and the applied analysis tool are shown.

2.1. From the feasibility of the project plan to prediction of the project management success and back

In contrast to evaluation of the project feasibility, predicting the success of a project is a more challenging task. Although the feasibility of project plans is satisfied if they fulfill the requirements, for the success of a project, it is also essential to satisfy the stakeholders and to meet their predefined expectations with the project outcome. Therefore, when specifying a model to predict the project success, it is important to score not only the realized tasks but also the whole project outcome.

The perception of success (or failure) could be divergent for different stakeholders, and this perception could also change over time[33]. concluded the lack of a uniform set of acceptance and success criteria that is applicable for every project. In terms of the success of the project management, the technical side, namely, cost, duration, and quality/scope, is often complemented by soft factors and skills of the people-related side, namely, political, social and cultural issues, how the delivered product is welcomed and used, and how well the results dovetail with the strategy of the sponsor/project owner/customer.

Hughes et al. [33] also state that despite several studies ascertaining that the reason of failure emanates from poor project management, they omit to indicate that this originates from incorrect use of the methodology or that the method itself is unsuitable for that particular project. In this paper, we use a vendor perspective and only deal with the project management success, the (hard) technological aspects of project performance regarding the duration, cost and quality/scope requirements, and its link to the applied project management methods. This approach is parallel to the concept of efficiency by [21], where the authors distinguished the efficiency (the project meets all internal requirements for cost, margins, asset utilization, and other efficiency measures) from the effectiveness (it satisfies or exceeds all customer expectations).

Since the satisfaction with the expected outcomes can only be estimated, the extended sense of the project feasibility is used instead of project success. However, our model is closer to the quantitative definition of project success than that of traditional feasibility because our model considers the customer's stated requirements through the project score.

This approach regards the project plan as infeasible or failed if *Process failure* (i.e., the system delivery has failed to meet its defined criteria in terms of time, budgetary constraints, and schedule) or *Correspondence failure* (i.e., the system does not meet all of its goals and quality criteria and the implemented system does not correspond to the requirements) occurs. The other two categories of [44] are not considered in our model because the *Interaction* and *Expectation failures* are outside the vendor's responsibility.

One of the most interesting results of the Chaos Report [56] was that the IT projects managed by *agile project management approaches* were 3

times more successful than traditional or waterfall-type projects. This considerable result is confirmed by other surveys and scholars [see, e.g., [7,18,41,70]]. However, hybrid approaches, such as the combination of traditional and agile project management, are not explored, while several case studies [see, e.g., 23, 31], surveys [see, e.g., 24, 68] and studies [see, e.g., 42, 65] indicate that usually a mixture of traditional and agile approaches are followed. Although [51] and [58] have stated that there is no superior project management approach for all kinds of projects, interesting questions remain regarding *why the mixture of agile and traditional approaches is so popular and whether the hybrid approach decreases or increases the probability of a project to succeed*.

2.2. Software project risk

Failing to understand and manage (software) project risk can lead to a variety of problems, including cost and schedule overruns, unmet customer requirements, and products that are not used or do not deliver business value. In accordance with the ISO 31000:2018, we use the term risk regarding the effects of uncertainty on the objectives that result in a deviation from the expected.

When managers deal with risk, they seek to influence their environment to reduce negative outcomes [see, e.g., 66]. Advocates of software project risk management suggest that project managers should identify and control these factors to reduce the chance of project failure.

Studies in the last two decades have described many risk management methods. Elsayah et al. [26] adopted a risk matrix combining probability and the influence of expert judgment. Chatterjee et al. [14] integrated fuzzy logic and the analytic hierarchy process (AHP) in the risk evaluation of projects and project portfolios. Concentrating on agile projects, Odzaly et al. [48] developed an agent-based risk tool that identifies, assesses and monitors risk. In open source risk management software, Ponsard et al. [52] incorporate Monte Carlo simulation and AHP to evaluate and prioritize risk mitigation measures. Since the agile approach divides the project into small pieces, the risk identification and assessment is more frequent than the assessment in the initial and planning phase of the traditional project management approach. Fu et al. [30] built a matrix-based risk evaluation method that subsequently models the possible interdependencies between risk factors. Our method combines the Monte Carlo simulation, risk factor interdependencies, and risk evaluation in contracting and planning as well as during the tracking phase.

Risk evaluation and analysis methods [see, e.g., 32, 43, 49] focus on the effects of changes in project parameters, such as changes in demands of resources, time and cost; however, none of these methods addresses the modeling of the change in customer requirements regardless of its high impact on project success, particularly in the case of IT and R&D projects and portfolios [see, e.g. 25].

Even if they treat the changes in the customer's requirements through a software development project, these methods focus only on the risk factors; therefore, these methods do not model the connections among project objectives, stakeholders and the risk factors.

The present paper, to our best knowledge, provides the first exposition that applies the so-called meta-network analysis (MNA) technique [67,73] for managing software development projects. MNA can dynamically model the dependencies and interdependencies between and among the following: risk factors, such as delays and cost overruns; the objectives, such as goals and requirements of stakeholders; and the stakeholders themselves, such as project managers (i.e., different kinds of agents), developers, and customers. The original version of the MNA specifies deterministic connections among risk factors and among risk effects and objectives. Nevertheless, in an agile and hybrid project environment, almost everything is flexible, such as the dependency between tasks, task occurrences, and project objectives. For example, depending on the implemented project management approach, lower-priority tasks can be excluded from a project; time delays of excluded tasks have no impact on project duration, and thus, the

corresponding nodes of the meta-network need to be removed or disabled. The proposed matrix-based version of the meta-network analysis consequently treats stochastic connections between elements.

To model the changes in customer requirements, the proposed framework simulates changes in the score (i.e., priority) of task completions, in addition to the uncertainties of the project parameters. This paper proposes agents (software algorithms to model project management approaches) to manage the aforementioned different kinds of changes and to try to maintain deadlines and budgets simultaneously. The simulation results show which approach should be used to manage various projects and different kinds of risk effects.

2.3. Matrix-based project risk management techniques

Similar to the emergence of matrix-based project planning techniques, the matrix-based risk management techniques have also been developed. Fu et al. [30] and Fang and Marle [28] proposed a matrix-based model to analyze the impact of risk propagation and evaluate the resulting risks. These methods subsequently handle the interdependencies between risks; however, they cannot treat the dependencies between risk factors and risk effects or the dependencies between risk effects and objectives. To date, a matrix-based representation of meta-network analysis has not been used. Just as network-based project management techniques are generalized by matrix-based techniques and introduce flexible relationships, Section 3 reveals that matrix-based risk management techniques can also generalize the network-based risk management techniques, such as meta-network-based techniques.

In the case of the matrix representation of MNA, a multiple-domain matrix (MDM) technique [27] should therefore be used. In this case, MDM is an adjacency matrix of the MNA, where domains on the diagonal represent the dependencies within each subnetwork (i.e., domains) of the meta-network. Such subnetworks are the set of risk factors (f_1, \dots, f_n , e.g., the changes in time, cost and resource factors of a given task); the set of risk effects (e_1, \dots, e_m), such as an overrun of the project duration and budgets; the set of objectives (o_1, \dots, o_k), such as the minimal project duration, minimal cost demands, and maximal quality; and the set of stakeholder requirements (s_1, \dots, s_l), such as the maximal number of WIPs and the maximal project scores. The off-diagonal domains can represent the interdependencies between subnetworks (see Fig. 1).

The matrix-based representation can specify not only a binary dependency between nodes but also the off-diagonal cells that can take values on the interval [0,1] and can model the risk propagation between risk factors or, e.g., between a risk factor and a risk event.

In the proposed matrix representation of MNA, the diagonal values can also be specified as a priori probabilities and the so-called conditional risk values can be simulated or calculated by Bayesian logic. With two-step Monte Carlo analysis, first, the risk factors are selected according to their a priori probabilities, and only the selected risk factors and their dependencies are considered at the next phase.

2.4. Project management approaches and their agent-based based implementations

The nature of the agile and hybrid projects, such as involving customers in the development process, ensuring strong executive support, and providing the ability to cope with emergent requirements, requires adaptive and flexible thinking for project management. In the agile project management (APM) approach, the completion of the project is more flexible, and the project structure can adapt to the changing customer requirements; see Fig. 2. In all agile project management methods, project plans (i.e., backlogs) are split into smaller parts in order to be able to manage flexible agile projects. For example, one of the most popular APM methods, the SCRUM approach, suggests sprints that have to be completed within 2–5 weeks, while the other well-known method, KANBAN, restricts the number of work-in-progress activities

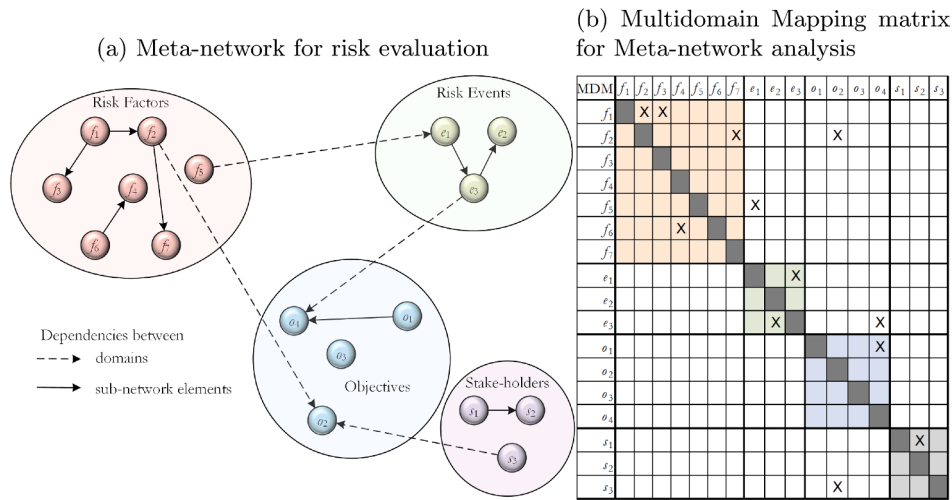


Fig. 1. Meta-network analysis and its matrix representation ('X' represents the arcs (i.e., connections) between nodes (i.e., variables)).

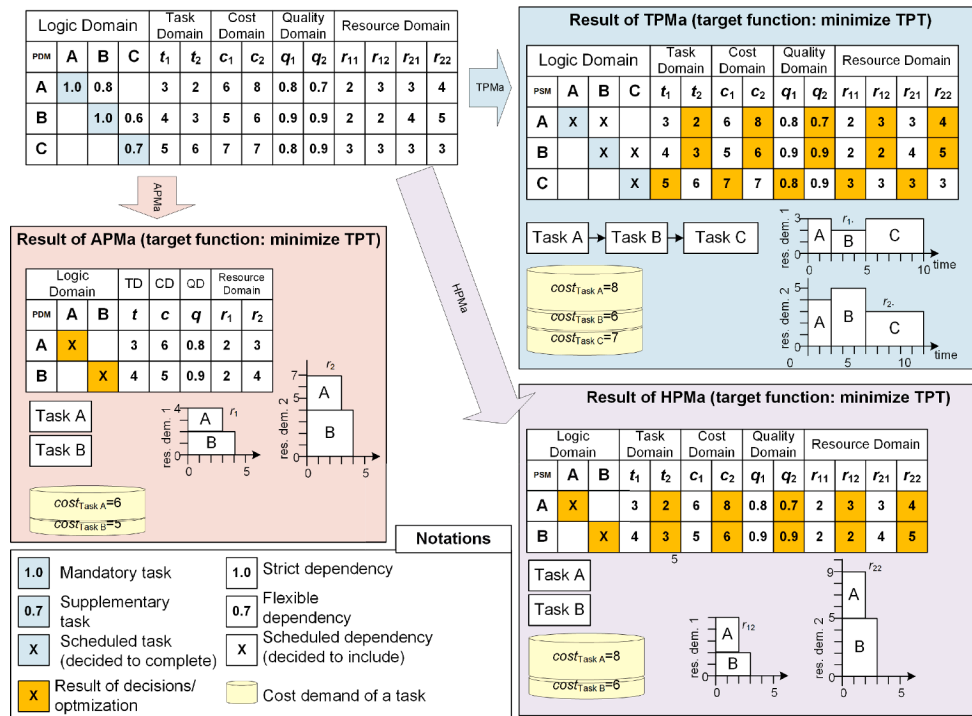


Fig. 2. Comparison of project management approaches and their agent-based implementations when the target function is the minimal total project time. (t_j, c_j, q_j represent time/cost demands/quality parameters, respectively, of completion mode j , r_{ij} is the resource i of completion mode j).

[22].

In traditional project management (TPM) approaches (such as construction projects or software development projects that follow a waterfall life cycle), the question is how much the realization of the requirements will cost. Therefore, while the scope is given and has to be completed, the time, cost and quality are convertible if necessary. This approach allows more than one completion mode [16] (technologies that require different time/cost/resource demands). In the agile project management (APM) approach, the question is how many of the features¹ can be included within the given budget and time interval (e.g., in a sprint). The goal is to realize the scope to the highest possible degree.

The TPM approach is widely supported by traditional project

scheduling methods [see 10, for an excellent summary of traditional methods]. Nevertheless, all of these methods are based on a fixed logic structure or a set of predefined alternatives [54,55]. In contrast to traditional techniques, the agile approach allows and sometimes requires restructuring the project. One of the main priorities of this method is to prioritize activities. Mandatory tasks have to be completed within a sprint (e.g., if the SCRUM method is followed) or within 2–3 sprints (e.g., if the KANBAN method is followed). Lower-priority activities can also be specified by other stakeholders. Nevertheless, if a sprint is specified and started, new tasks and new requirements can be implemented only in the next sprint.

Hybrid approaches are usually a mixture of agile and traditional project management approaches. An important distinction concerns agile projects that are embedded in traditional project plans [62], in contrast to agile and traditional approaches that are combined [59] to

¹ In the view of project management, to implement a feature is a task.

manage single projects. Kosztyán and Szalkai [38] explored the advantages and shortcomings of the combination of two worlds: agile and traditional project management approaches and techniques. However, as Pich et al. [51] and Sommer et al. [58] have previously stated, there is no superior project management approach. The choice of an adequate project management approach depends on the project's nature. Since all the traditional, agile and hybrid project scheduling approaches can be implemented by computer algorithms [39], the next step is to study which project management approach is the most suitable for different IT projects. While our current focus is on IT projects, the proposed simulation tool can also consider different kinds of other projects. Therefore, this model can be useful to estimate whether agile and hybrid approaches can be successful for other flexible but non-IT projects.

Formally, in TPM, there is a scope that has to be achieved within a given time and certain budget, but time, cost and quality can vary according to requirements. The objective function could be the minimal total cost, maximal quality, balanced resource demands, or minimal project duration [see, e.g., 10], in addition to the goals in Fig. 3. TPM can apply different kinds of trade-off methods in order to balance time/cost/quality/resource demands [46]. The extension of the trade-off problem, which was implemented as a TPM agent, does not require the trade-offs between resources [16]. This so-called multimode resource-constrained project scheduling problem (MRCPSP) only specifies so-called technologies or completion modes that contain different time, cost and resource demands for every task. In this paper, we used this algorithm to implement TPMa.

In the case of MRCPSP, the objective function could be the minimal total cost or minimal project duration. Since trade-off and MRCPSP models have been developed for traditional management approaches, they work in a fixed logic structure. For agile project planning deadlines, resource and cost availability are fixed [see 17] (see Fig. 2), and the project structure may be more flexible. The goal could be the realization of as many tasks as possible regarding the importance of realizations and the flexibility of project structures. Nevertheless, minimized total project time, minimal total project cost or balanced resource demands are also relevant target functions for the agile project management approaches (see Fig. 2).

All the MRCPSP (by Creemer's [16] algorithm (hereafter TPMa)), agile (by Kosztyán's [37] algorithm (hereafter APMa)) and hybrid (by Kosztyán-Szalkai's [39] algorithm (HPMa)) scheduling methods are regarded as simplified models of project managers' decisions, and each are realized by a computer program (agent).

In this paper, agents imitate project managers, the real decision-makers, who have to organize the project within the constraints (see an example in Fig. 2)

Fig. 2 shows a comparison of project management agents through an example, where the target function is the minimal TPT. The figure shows that even if constraints are not defined, different results can be obtained with different agents.

These computer programs (agents) are based on scheduling, cost minimizing and resource allocation algorithms. The aim of these agents is to specify a project scenario from a stochastic project plan that is feasible in the extended sense. This project scenario can be represented by a project domain matrix (PDM) (see the example in Fig. 2).

The *traditional project management agent* (TPMa) can use the traditional time/cost trade-off or multimode resource constraint project scheduling methods in order to reduce the time and/or cost demands [see, e.g., 16] of the project (see Fig. 2) and can use resource allocation and/or resource leveling algorithms for specifying a time and/or resource-constrained resource allocation if it is necessary, but the logic plan of the project is fixed (see the results of TPMa in Fig. 2)) and independent of the task priority. Therefore, the project plan will not be restructured. Unfortunately, in the scenario of applying the trade-off and MRCPSP methods, the time/cost/resource demands cannot be decreased sufficiently without restructuring the project plan [37].

The *agile project management agent* (APMa) can ignore supplementary

task completions (see the results of APMa in Fig. 2) and it can restructure projects if the uncertain task dependency is ignored. In this way, the logic plan can be restructured considering the management requirements [see, e.g., 37]). Nevertheless, in the restructuring, the lower priority but otherwise important tasks might not be completed, which can reduce customer satisfaction.

Hereafter, the algorithm for solving the hybrid multimode resource-constrained project scheduling problem (HMRCPSP) [39], which is a combination of the traditional and agile algorithms (see the results of an example of HPMa in Fig. 2), is referred to as the *hybrid project management agent* (HPMa).

This paper compares the success (i.e., extended sense of feasibility) of different kinds of project management approaches on different kinds of real project structures and various simulated risk factors. A novel matrix-based risk assessment tool is also proposed.

2.5. From Monte Carlo simulations to survival analysis

Monte Carlo simulation (MCS) is one of the most frequently applied methods of risk management. This is a useful technique to simulate project risks and uncertainties. In MCS, risk effects, such as delays, cost overruns, and overwork, can be simulated by changing the time/cost/resource demands of the tasks [40]. In MCS, task demands follow theoretical or empirical distributions. By combining MCS with matrix-based techniques, the interdependencies of the risks can also be modeled (see Section 2.3). In the case of flexible project structures, the project can be restructured [38,39], which until now has received little attention in the literature, but this extension is crucial for handling flexibility, such as in agile and hybrid projects.

Survival analysis is a branch of statistics for analyzing the expected duration of time until one or more events happen, such as failure in mechanical systems, or in this case, project failure. In this study, the survival analysis attempts to answer questions such as the following: what is the population proportion of a project plan that can be managed, and which ones will fail? Can multiple causes of failure be taken into account? How do particular circumstances or characteristics increase or decrease the probability of survival? The main focus of survival analysis is on time-to-event data. Nevertheless, similar to the time-to-event data, the stratification of risk factors can also be modeled.

Typically, survival data are not fully observed, rather censored. Due to the presence of the censoring in survival data, the standard evaluation metrics for regression, such as the root mean squared error and R^2 , are not suitable for measuring the performance in random forest-based survival analysis [34].

Survival data are commonly analyzed using methods that rely on restrictive assumptions such as proportional hazards. Further, because these methods are often parametric, nonlinear effects of variables must be modeled by transformations or expanding the design matrix to include specialized basis functions. Since following a meta-network analysis means that the analyzed risk factors can be related to each other arbitrarily, a robust flexible method, Iswaran et al.'s [34] method, namely, "survival random forest", is applied.

The main advantage of the random forest-based survival analysis (RFS) method is its robustness, such as indicated in its handling of the correlation and dependency between the risk factors and the flexibility it affords for being combined with meta-network analysis.

3. Methods

According to the research questions, the main goal was to compare project management approaches in order to study which one allows the most projects to survive the changes in task demands and the changes in the customer's requirements (see RQ_1). At the next stage, for survived projects, the question is to determine which project planning and scheduling approaches can mitigate to the greatest extent the effects of project risk factors (RQ_2). Finally, what is the importance of the risk

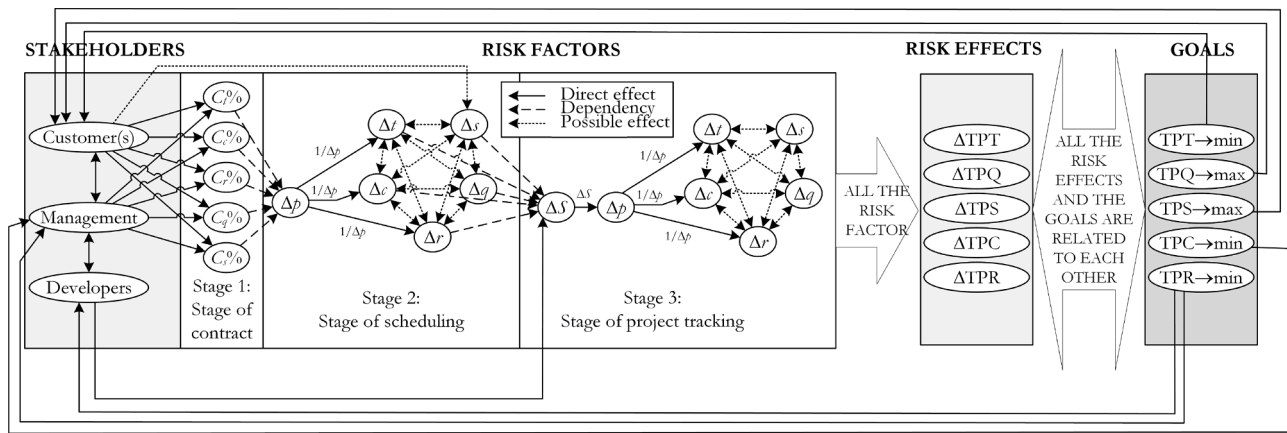


Fig. 3. The proposed meta-network structure.

factors to the sensitivity of project schedules (RQ_3₃)?

3.1. Data sources

The first problem was to select adequate project plans from a project database because neither known project generators (such as ProGen [36], RanGen I [19], and II [64]) nor open project data sources (such as MMLIB [50] and PSPLIB [36]) distinguish mandatory and supplementary tasks or consider strict and flexible dependencies. Therefore, there are no score values linked to task completion or task dependencies. Nevertheless, without considering flexible dependencies and priorities of task completion, the flexible project plans cannot be modeled because lower-priority (supplementary) tasks cannot be postponed, and the project plan cannot be restructured. Since there is still no real project database that contains an empirical distribution of the priorities or the flexible dependencies, the selection of tasks/dependencies and priorities followed a uniform distribution.

The second problem is that the quality parameters are neglected and the cost parameters are also usually missing from the project plans. Nevertheless, these project databases and project generators have been validated and applied in several publications for testing and comparing algorithms; therefore, we decided to use the logic network and resource demands, and we extended the project plans with cost, quality and score parameters in the simulation. The costs are considered as the cost of resources; therefore, they are calculated as follows:

$$c_{i,w} = t_{i,w} \cdot C \sum_{\rho} r_{i,\rho,w} \quad (1)$$

where $c_{i,w}$ is the (resource) cost of task i completed by mode w , and $r_{i,\rho,w}$ is the resource demand for resource ρ of the task i with completion w . The C is the specified unit cost (e.g., EUR / hour). In the simulation, C is specified as 1.

When calculating quality, the Babu and Suresh's [3] cost-quality trade-off formula is used.

$$q_{i,w} = c_{i,w} / c_i^{\max} \quad (2)$$

When the cost is maximal, the relative quality is 1; however, a lower cost provides lower quality. According to Kosztyán and Szalkai [39] the (relative) total project quality (TPQ) is the ratio of the sum of quality parameters of implemented tasks per the sum of maximal quality parameters of all tasks. This value is maximal if all tasks are implemented in the best quality way. However, this value is decreasing if either a task is ignored/postponed or even implemented but with lower quality.

These formulas were only required when cost demands and quality parameters are generated for the tasks; however, these values can be modified in the phase of simulation.

3.2. Selection and simulation criteria for initial projects

The aim of the selection and generation of initial project plans is to meet as much as possible the expectations for (IT) software project plans, especially the features of agile and hybrid projects:

- CR_1 *Criterion of project structure*: In previous studies, Tavares et al. [61] and Vanhoucke [63] showed that software projects usually contain more parallel tasks; therefore, according to Tavares et al. [61] and Vanhoucke [63], the number of parallel tasks is greater than the number of serial tasks² Nevertheless, several agile methods, such as the KANBAN and SCRUMBAN methods, limit the number of parallel work-in-progress (WIP) tasks, and allow only 3–5 WIP tasks. Therefore, in the simulation, the number of WIP tasks must be lower than 5.
- CR_2 *Criterion of task numbers*: Projects are usually separated into smaller autonomous subprojects (sprints) [see, e.g., 22] that should be completed within 2–5 weeks; therefore, the number of tasks is limited and should not be greater than 50.
- CR_3 *Criterion of resources*: It contains at least two types of renewable resources (e.g., programmer and tester)
- CR_4 *Criterion of completion modes*: It contains three completion modes to apply MRCPS, and in this manner, it also tests the performance of the hybrid approaches.

The abovementioned criteria were true only for the simulated IT projects. Nevertheless, control group project plans, whose characteristics are closer to construction projects or the traditional waterfall software development projects, are also included. Three kinds of datasets were selected. The logic networks, i.e., tasks and their dependencies, of Dataset A is from standard project databases. Project plans of Dataset B are generated by the standard project generator software ProGen, and project plans of Dataset C are from a project database containing real-life project plans. Logic plans and resource demands are left untouched; however, for the cost and quality domains, formulas (1)-(2) are also used to calculate the initial cost and quality parameters.

Dataset A contains selected data from the project databases PSPLIB (j30 dataset) and MMLIB (MMLIB50 dataset). Database selection was performed based on the specified criteria (CR_1)-(CR_4), including the number of activities and

² Following the simulations of Tavares et al. [61], $i_2 = (m-1)/(n-1) \in [0.2, 0.3]$, where m is the number stages in a topological ordered network and n is the number of tasks. $i_2 = 1$ if all tasks are completed in a serial manner, and $i_2 = 0$ if all tasks are completed in parallel.

serial/parallel indicators, of which the values best fit the projects in the IT sector. To select the appropriate data instances, we calculated the average values of several project network topology indicators³ of both real-life IT projects and Construction projects (also found in Dataset C). Then, the same set of indicators for the instances of PSPLIB's "j30" and "MMLIB50" datasets were calculated. By minimizing the standard deviation between the results, we could filter the artificial project instances that were closest to the projects in the IT and construction sector. Ten logic plans have satisfied the above specified criteria the most. Since project duration and allocated resources over time depend mainly on the structural parameter i_2 [see, e.g., 2,11], for the control group, project plans were selected with the indicator $i_2 \sim 0.4$, which is more specific to the construction projects.

The proposed Dataset A contained the following: (for specifying IT projects: j3031_7; j3035_10; j3042_1; j3031_5; j3064_10; J5063_4; J5046_2; J5043_5; J5050_1; J5061_1; for specifying construction and waterfall projects: j3028_8; j3031_5; j3031_7; j3035_10; j3042_1; j50101_3; j5073_4; j5087_5; j3089_1; j3089_5).

The project plans in groups 1–10 emulated the IT projects, where $i_2 = 0.2$, whereas the control groups (11–20) included a selection of 10 additional projects that emulated the construction project or the traditional waterfall software development projects. The groups of 1–5 and 11–15 project plans contained 30 tasks, while those of groups 6–10 and 16–20 had project plans that contained 50 tasks.

This database contained 3 completion modes and two kinds of renewable resources.

Dataset B In addition to the selected instances from existing standard datasets, project instance generators have been considered as another source of project data. The widely accepted generator ProGen [36] was selected for our work because it allows the generation of project data with multiple execution modes and supports a wide range of controllable problem parameters [19,20,35]. Ten project structures were generated regarding the criteria (CR₁)-(CR₄), where i_2 was 0.2. Ten projects for the control group were also generated, where i_2 was 0.4. Half of the generated projects have 30 tasks; the other half of the projects contain 50 tasks.

Both the project generator ProGen and the project dataset MMLIB contain only the duration and resource demands of the completion modes; cost and quality are always missing, and because the main cost of the IT project is the cost of resources, the quality parameters are estimated by using formulas (1)-(2).

Dataset C consists of empirical project data from the database presented by Batselier and Vanhoucke [6]⁴. **IT projects include the following:** C2011-05 Telecom System Agnes; C2011-07 Patient Transport System; C2011-09 Commercial IT Project; C2012-01 Manufacturing Tool Cost Module; and C2012-09 Digipolis Talent Management Suite. **For control groups, the projects include the following:** C2011-08 Sports Center Tiel; C2011-10 Building a House; C2012-02 Nut Mixing Station; C2012-14 Sluiskil Tunnel; and C2012-17 Building a Dream.

The considered IT and construction projects contained time, cost and resource demands but did not contain completion modes. Therefore, to compare the project

management approaches, other completion modes were generated. We considered the original demands, and the generated demands ($d_{i,w}$) for task i and completion w were approximately the original demand (d_i). Formally: $d_{i,w} \in [0.8 \cdot d_i, 1.2 \cdot d_i]$.

Since quality parameters are missing from every known project database, they have to be calculated according to the quality-cost trade-off functions (see Eq. (2)). After selecting project plans (see the 20 selected project structures in Dataset A and the 10 selected project structures in Dataset C) and generating 20 project plans in Dataset B, the original database contained 50 project plans. Half of them were considered an IT project, and half of them were in the control group. In terms of project planning, the main difference of the selected project group and the control group was the project structure. Nevertheless, the distinction between mandatory and supplementary tasks and the distinction between the fixed and flexible dependencies between tasks are also missing from the original datasets. Therefore, the flexibility parameter ($F\%$) is set to be 0%, 10%, 20%, ..., 50%, which means that the $F\%$ of task completion and task dependencies is selected to be flexible. Score values, which reside in the interval $[0,1]$, are linked to them. The final database had $50 \times 6 = 300$ PDM matrices.

3.3. The proposed meta-network structure and the stages of risk simulation

The proposed meta-network structure is a (meta)model for project risk management. It has four parts: stakeholders, risk factors, risk effects, and goals. In this framework, three groups of stakeholders are specified: the customers, who order the software; the management, who manage the progress of the project; and the developers, who make the software. Risk factors address the change of constraints in the contract phase (stage one), the change of demands at the scheduling phase (stage two) and those at the project tracking phase (stage three). These risk factors may influence all the risk effects, such as the delay of the project duration (ΔTPT), the overbudget situation (ΔTPC), the changes in resource demands (ΔTPR), the changes in project quality (ΔTPQ) and the changes in the project scope, which is quantified by the total project score (ΔTPS). The stakeholders may have different goals that are partly or fully contradictory to each other. Usually, customers want the highest quality software ($TPQ \rightarrow \max$) with considerable functionality ($TPS \rightarrow \max$), but as soon as possible ($TPT \rightarrow \min$). Management tries to minimize the budget ($TPC \rightarrow \min$) and similar to the developers, they try to decrease the use of resources ($TPR \rightarrow \min$) as much as possible (see Fig. 3). Nevertheless, customers are usually not interested in decreasing the project cost or reallocating resources while the project budget can be maintained.

The proposed simulation framework has three stages. In *stage one* constraints, such as the time ($C_t\%$), cost ($C_c\%$), quality ($C_q\%$), score ($C_s\%$) and resource ($C_r\%$) constraints, are the results of the contract; therefore, in this stage, by an agreement with the customer, there is an opportunity to alter the constraints. According to the specified goals, managers can select the adequate project management approach, which is represented as an agent. An agent tries to produce feasible project plans. In addition to the feasibility, the scheduling properties, such as scheduling performance (project duration, project cost and resource demands per adequate constraints), are also explored. **In stage one the contractual stage, the emergence of bargaining between customers and developers is modeled.** More restrictions can produce fewer completed tasks and lower quality but can produce a lower budget and lower project duration. More requirements can produce more completed tasks but can produce a greater budget and greater project duration. Knowing the priority and completion mode data, the minimal and maximal value of the total project cost (TPC), the total project time (TPT), the maximal value of total project resources (TPR), the total project qualities (TPQ) and the total project scores (TPS) can be specified

³ Such as $i_2, i_3, i_4, i_5, i_6, OS, CNC$; for definitions, please refer to Vanhoucke et al. [64]

⁴ Database url: <http://www.projectmanagement.ugent.be/research/data/realdata>

following Kosztyán and Szalkai [38]. Constraints are the subject of bargaining (see the rate of constraints $c_x\% \in [0, 1]$, where $c_x\% = (c_x - TPX_{\min}) / (TPX_{\max} - TPX_{\min})$, $c_x \in [TPX_{\min}, TPX_{\max}]$ is the time/cost/resource/score or quality constraint). Furthermore, TPX can be TPT, TPC, TPS, TPR or TPQ.

The target functions are either $TPT \rightarrow \min$ or $TPC \rightarrow \min$ or $\overline{TPR} \rightarrow \min$ or $TPQ \rightarrow \max$ or $TPS \rightarrow \max$, $\overline{TPR} = \text{mean}(TPR) = \frac{1}{r} \sum_{\rho=1}^r TPR_{\rho}$. At the end of this stage, a set of feasible project plans managed by TPMA / APMA / HPMA is specified.

In *stage two* (the scheduling stage), only the feasible (i.e., survived) project plans are considered (see dashed lines between constraints in stage one and the project properties in stage two in Fig. 3). At this stage, the time/cost/resource/quality and score demands are varied a.) independently and b.) considering interdependencies modeled by the matrix representation of MNA. Due to the MNA, the extreme or shock effects can also be modeled. Shock effects are limited in range and in the number of affected tasks but have higher impact on these. In the planning phase, such an effect could be the replacement of a vendor, who delivered software or hardware solutions to some of the tasks, and the new vendor has different costs, delivery time or different resources that are required to implement its product into the project. In the tracking phase, a virus infection or system shutdown could be typical examples, where only those tasks are affected that are in progress when the event occurs. In this simulation, a two-step Monte Carlo analysis is used, where the set of tasks that will be modified are specified first. The selection of tasks was random. In this simulation, this selection parameter is specified as $\Delta p = 10\%$ and $\Delta p = 100\%$. When all tasks are modified ($\Delta p = 100\%$), the uncertainty of planning is analyzed; when only 10% of tasks are affected ($\Delta p = 10\%$), the *shock or extreme effects* can be modeled. In the latter case, according to the literature [see, e.g., 71], the modification of task durations (Δt), cost demands (Δc), and resource demands (Δr) will be 5–10 times larger than the effect of the uncertainty. To avoid the overemphasis of the shock effect in the comparison, in the simulation, the impact of shock is inversely proportional to the affected range (Δp) (see Fig. 3). This means the impact is 10 times that of the (beta-distributed) variation that models the uncertainty, but it concerns just 1/10 of the tasks, so a more focused effect is compared to a more distributed effect, while the cumulative effects in the two cases are commensurable. In the case of $\Delta p = 100\%$, we focus on the estimation uncertainty, where every task demand can be uncertain; for $\Delta p = 10\%$, we concentrate more on the risks of implementation, where not all demands are varied, but this variation can be much greater than the uncertainty of the estimations.

A novel element in the proposed framework is the sensitivity analysis of the task priorities (Δs). Currently, the use of the conditional risk factor (Δp) is very rarely used in simulations; nevertheless, based on our knowledge, none of the risk management methods model the varying of the customers' requirements and priorities as the proposed framework does. The varying priorities are specified by changes in diagonal values in the logic domain of PDM. The off-diagonals are specified by the task completions' probability according to the varying customer requirements. Following the practice of sensitivity analysis in project management, all changes in parameters, such as time, cost, and resource demands as well as the quality and score parameters, follow a β -distribution, where the most likely value was the original value of the parameters, the optimistic value was 90% and the pessimistic value was 130% of the original value. This set of parameters follows the underestimated demands observed in practical life.

Stage one and stage two simulate only the modifications of project plans according to the varying customer requirements in order to answer RQ_1-RQ_2. In *stage three* (the tracking stage), the process of the implementation is simulated. Here, completed tasks are not varied; however, work-in-progress tasks and unstated task demands and priorities are varied in order to answer RQ_2-RQ_3.

3.4. Implementation of the simulation framework

Fig. 4 shows the proposed simulation framework. In this simulation, the influence of risk effects, such as the modification of constraints (see stage one) and overruns of cost and time (stage two and stage three) are mitigated by project management agents. The properties of the survived projects handled by different kinds of project management agents and their count are compared for all of the five specified goals.

3.4.1. Stage one - the stage of project contract

At stage one, time/cost/quality/resources and score constraints are set to be $\frac{1}{3}$ or $\frac{2}{3}$ of the theoretically available range of the project demands. These parameters simulate two deals. One of the deals is more restricted, the other one is more relaxed. In this way, we obtain 2^5 (number of possible constraint sets) $\times 50$ (number of projects) $\times 6$ (levels of flexibilities) = 9,600 problems. For all of the five specified target functions, we obtain $9,600 \times 5 = 48,000$ scheduling problems. These problems are solved by TPMA, APMA and HPMA agents. Therefore, we gain $3 \times 48,000 = 144,000$ results. The results solved by agents are compared by their rate of feasibility (feasible projects/all projects) and by their scheduling performance (see Eq. (3)).

$$TPX\% = \begin{cases} \frac{c_x - TPX}{c_x - TPX_{\min}}, & \text{if } TPX \in \{TPT, TPC, TPR_{\rho}\}, \rho = 1, 2, \dots, r \\ \frac{TPX - c_x}{TPX_{\max} - c_x}, & \text{if } TPX \in \{TPQ, TPS\} \end{cases} \quad (3)$$

where $c_x \in \{c_t, c_c, c_r, c_q, c_s\}$.

Regarding the $TPX\% \in [0, 1]$, the greater value indicates better performance. If $TPX\% = 1$, it means that when optimizing, the best value (such as the minimal project duration, minimal project cost, minimal resource demands, maximal project quality or maximal project score) can be reached, whereas if $TPX\% = 0$ exists, only the constraint can be satisfied.

3.4.2. Stage two - the stage of project scheduling

Since infeasible project plans do not assume to pertain to any concluded agreement, at stage two (stage of scheduling), only the feasible solutions are surveyed. Two scenarios are explored: (1 - sensitivity analysis of uncertainty, i.e., $\Delta p = 1.0 = 100\%$) applies to the scenario when all parameters, such as time/cost/resource demands and score/quality parameters of tasks can be changed between -10% and 30% and parameters follow the three parameters (a, m, b) of the β -distribution, which is usually used in Program Evaluation and Review Technique (PERT) networks. The most likely values (mode, m) of the parameters in this distribution are the task time/cost/resource demands, which are specified in stage one. $a := 0.9m, b := 1.3m$; (2 - sensitivity to shock effects) applies to scenarios when only parameters of randomly selected tasks ($\Delta p = 0.1 = 10\%$) are changed, but these changes are $1/\Delta p = 10$ times of the uncertainty effect. Although the applied survival random forest method is not sensitive to the correlation between the risk factors, in order to explore the influence of correlation between risk factors (i.e., $\Delta t, \Delta c, \Delta r, \Delta q$, and Δs) to risk effects (such as $\Delta TPT, \Delta TPC, \Delta \overline{TPR}, \Delta TPQ$, and ΔTPS), a subgroup, where the mean correlation between risk factors is greater than 0.6, is also specified and explored. The ratios of changes on project parameters are calculated as follows:

$$\Delta TPX_{ij}\% = \frac{TPX_i}{TPX_j} \quad (4)$$

where $i = 2, 3; j = 1, 2$ is the number of stages. $TPX \in \{TPT, TPC, \overline{TPR}, TPQ, TPS\}$.

For example, $\Delta TPT_{ij}\% = 1$ or $\Delta TPC_{ij}\% = 1, \Delta TPS_{ij} = 1$ and means that due to the applied project scheduling (and in this case, risk mitigation) approach, the total project time/cost/resource/quality/scores

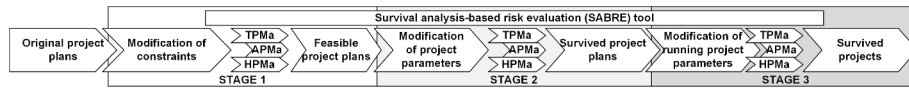


Fig. 4. The proposed simulation framework.

are not changed with the changes in the risk factors. If $i > j$, then $\Delta TPT_{ij}\% \geq 1$, $\Delta TPC_{ij}\% \geq 1$, $\Delta TPR_{ij}\% \geq 1$ and $\Delta TPQ_{ij}\% \leq 1$, $\Delta TPS_{ij}\% \leq 1$ can be assumed. The risk mitigation performance of the project management approach is better if this ratio is closer to 1.

The changes in the feasibility rate are also calculated as follows:

$$\Delta f_{ij}\% = \frac{f_i\%}{f_j\%} \quad (5)$$

where $f_i\%$ is the feasibility rate in stage i .

Similar to $\Delta TPQ_{ij}\%$ and $\Delta TPS_{ij}\%$, $\Delta f_{ij}\% \leq 1$

3.4.3. Stage three - the stage of project tracking

Stage three is based on the result of stage two. In stage three, all risk factors are used that are introduced in stage two. However, in this case, the rate of scheduled tasks ($S\% \in 0.25, 0.50, 0.75$) influences how many tasks are completed or are in progress. In stage three, only the remaining task parameters can be changed, and the agents have to mitigate the risk effects in order to keep the deadlines and the budget while minimizing the project duration or the project cost or maximizing the quality of the project.

Due to the different natures of the project management agents, we assume that the counts and the schedules of the survived project will be significantly different at the end.

Fig. 5 shows the operation of the stages of the SABRE via an illustrative miniature project. This project contains only one mandatory (A) and one supplementary (B) task, with two completion modes and two resources. Fig. 5 shows only the part of the simulation stages, where the applied agent is the HPMA, the applied target function is to minimize TPT and there is no correlation between the changes of the task parameters (risk effects). At Stage 1, different kinds of constraints are specified to simulate the negotiation (e.g., cost, deadline) between the vendor and the customer. Fig. 5 shows that if the HPMA cannot comply with all restrictions, in such cases, the contracting process miscarries and the vendor cannot undertake completing the project with the original customer specifications. In Stage 2, the deviations of activity resources or time demands from the planned values are analyzed as risk factors. If a project plan cannot be implemented with the chosen management approach without renegotiation of specifications, costs or deadlines, then it has no feasible solution, and it is deemed as an unsurvived project. In both survived and unsurvived project cases, the

causes can be followed alongside the branches. Fig. 5 shows that the miniature project can be solved only for the relaxed resource constraints (in Stage 1). If the flexibility is not changed in the scheduling stage (Stage 2), the project is more sensitive to resource and cost changes than to duration changes. However, if the flexible dependencies were to become fixed (e.g., because of the technology change), the serial completion would be more sensitive to task duration changes.

Table 1 shows the summary of risk factors and risk sources.

4. Results of the simulation

After the descriptive statistics in Section 4.1, the RQ_1: “Which project planning and scheduling approaches allow the most projects to survive the changes in task demands and customer requirements?” is answered in Section 4.2. Section 4.3 answers RQ_2, namely, “For the survived projects, which project planning and scheduling approaches mitigate most of the effects of project risk?”, and in Section 4.4, the last research question (RQ_3) is investigated: “What is the importance of the risk factors to the sensitivity of project schedules?”. In the last subsection, the threats to validity are discussed.

4.1. Descriptive statistics

Fig. 6 shows the results of the descriptive statistics of 48,000 scheduling problems, which are based on a set of 50 project structures.

Table 1 Sum of risk factors and risk sources.

Stage	Risk factor/source	Notation
Contractual stage (Stage 1)	Constraint strictness / more restrictive requirements	$C_t\%, C_c\%, C_q\%, C_s\%, C_r\%$
Scheduling stage (Stage 2) and Tracking stage (Stage 3)	Task demand uncertainty regarding the whole project	$\Delta t, \Delta c, \Delta q, \Delta s, \Delta r$
Tracking stage (Stage 3)	Shock-like, high degree changes concerning a narrow set ($\Delta p = 10\%$) of the tasks	$\Delta p \in \{0.1, 1.0\}, 1/\Delta p \cdot \Delta t, 1/\Delta p \cdot \Delta c, 1/\Delta p \cdot \Delta q, 1/\Delta p \cdot \Delta s, 1/\Delta p \cdot \Delta r$
Tracking stage (Stage 3)	Rate of completeness: Already completed tasks reduce the adaptability of the management approach	$S\% = \{25\%, 50\%, 75\%\}$

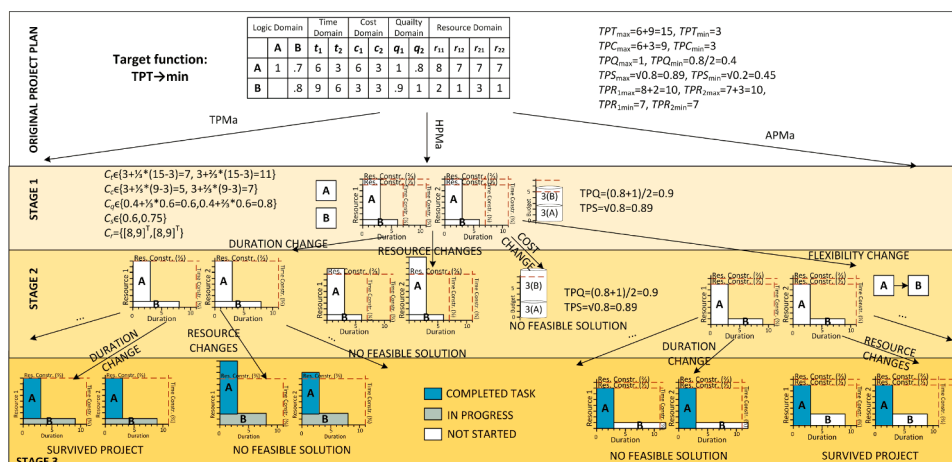


Fig. 5. Example of simulation process in SABRE.

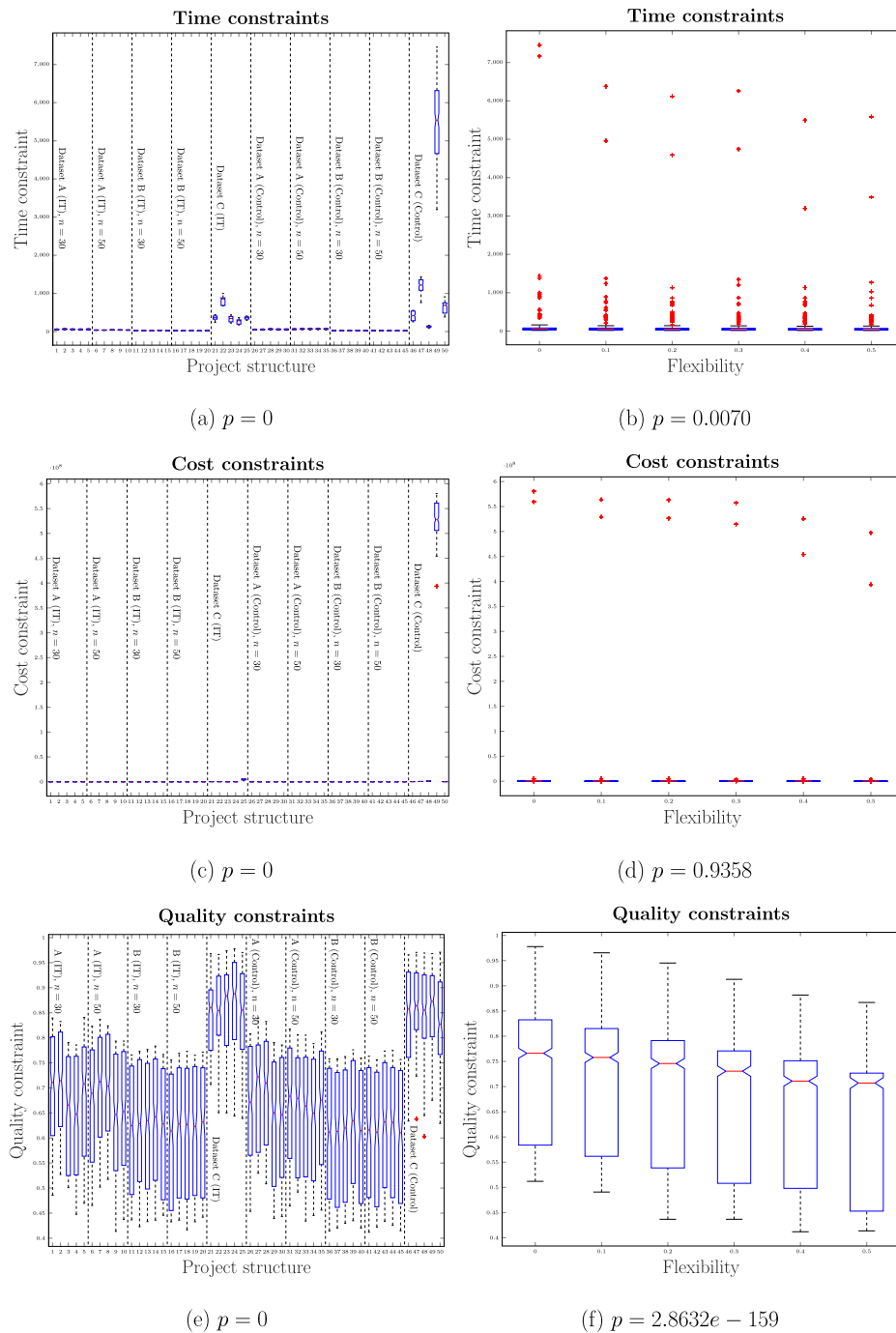


Fig. 6. Results of (M)ANOVA for constraints, project structures and flexibility.

The project structures of 1–25 consisted of generated and real IT projects, and the control groups (26–50) followed construction project structures. Since 0–50% of task completions and dependencies between tasks are considered flexible, the constraints were calculated individually for each scheduling problem (see Section 3.3) Fig. 6 shows the time, quality, score and resource constraints by project structures and by flexibility parameters. Constraints are specified at $\frac{1}{3}$ and $\frac{2}{3}$ of the theoretical range of project demands. These constraints were the same for all PMAs; therefore, they can be compared. However, the specification of constraints fits the possibilities of the project plans. Therefore, we can ascertain that the real projects have more time and cost demands (see project structures 21–25 and 46–50 in Fig. 6(a,c)). In that case, the

quality demands are also higher (see project structures 21–25 and 46–50 in Fig. 6(e)). On the other hand, the generated projects (from) have the highest resource demands (see project structures 15–20, 35–50 in 6(g)). From the MANOVA cluster, only one project structure (49) is shown to exhibit a relevant difference in constraints (compare 6(a) and 6(c) and 6(k)).

To compare the results of all the risk factors, such as changing the constraints and parameters, as well as the risk effects, such as feasibility and scheduling, the performance is considered in terms of relative values (ratios) (see Eqs. (3)–(5)). The results show that a risk analysis should also include real-life projects because their constraints may be different from project structures in a standard database. Nevertheless, from the

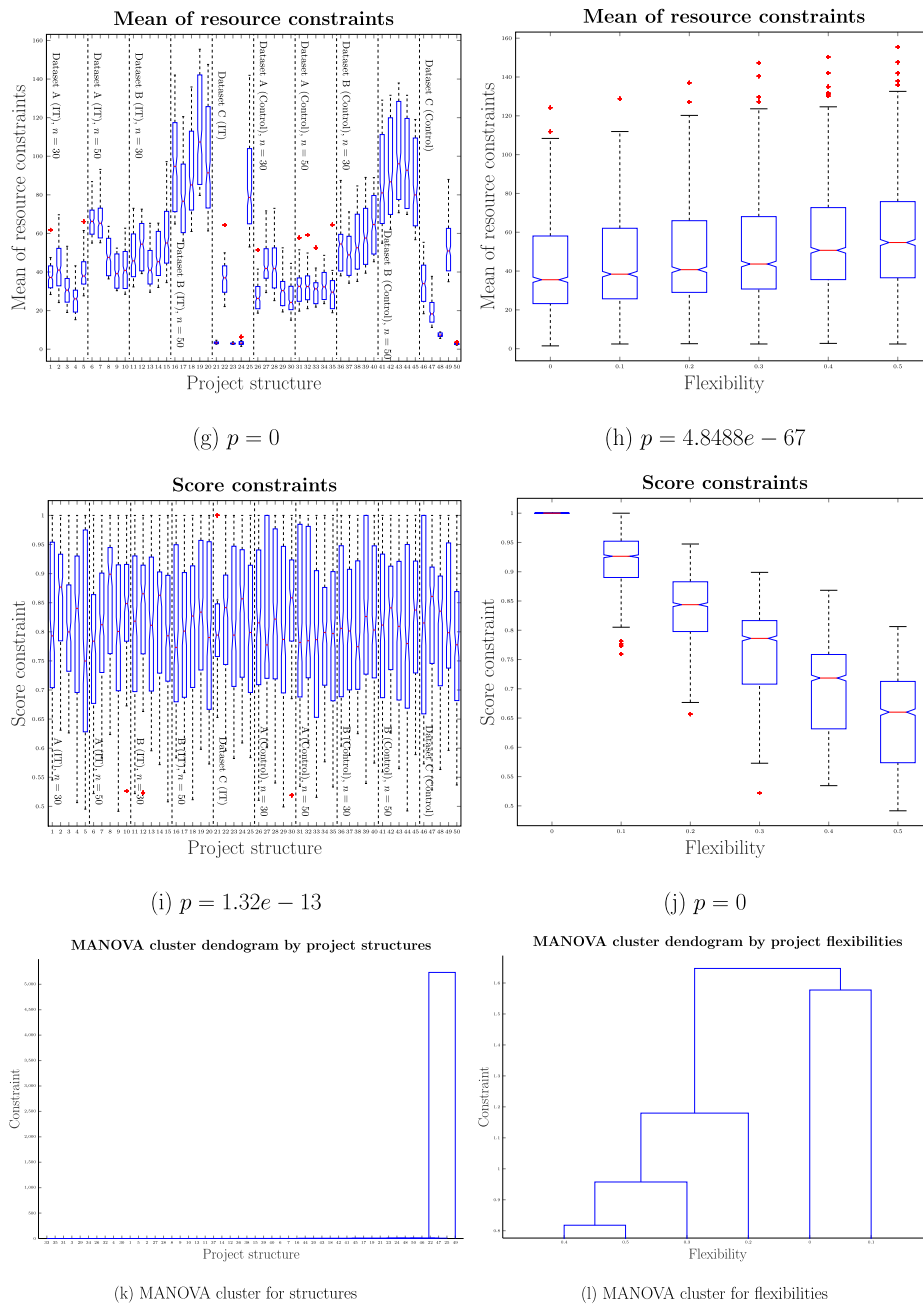


Fig. 6. (continued).

view of project constraints, the difference is lower between IT and non-IT projects. The other interesting results are that if a constraint is calculated by the proportion of a project demand, the absolute values of constraints are relaxed. The results presume that the more flexible projects can be managed with less project demand (see Fig. 6(d,f,h,j)). However, this can only be true if we also use flexible methods for scheduling.

4.2. Feasibility versus flexibility

Fig. 7 (a) shows the feasibility rates (i.e., survival rate) of project management agents by stages and flexibility. The survival rate gives the ratio of feasible project scheduling problems in the given stage managed by TPMA, APMA or HPMA. Stage by stage, increasingly fewer projects survive the changes in constraints (Stage 1), the changes in demands and structures in the planning phase (Stage 2) and in the tracking phase

(Stage 3). Especially in Stage 3 (see Fig. 7(b)), the TPMA is more sensitive to the changes in demands, while the flexible approaches are generally less sensitive (see Fig. 7(b)), even if the flexibility ratio is high (see Fig. 7(a)).

In line with Fig. 6(d,f,h,j), Fig. 7(a) shows that generally, the increase in flexibility increases the rate of feasibility for all approaches. However, this opportunity can be exploited primarily by agile and hybrid approaches. In addition, in cases of lower flexibility (< 20%), the TPMA manages more feasible projects than does APMA (see Fig. 7(a)).

The interesting result is that HPMA made better use of the opportunities offered by flexibility. HPMA makes more feasible projects than the agile approach.

4.3. Scheduling performance

When analyzing the scheduling performance of project management

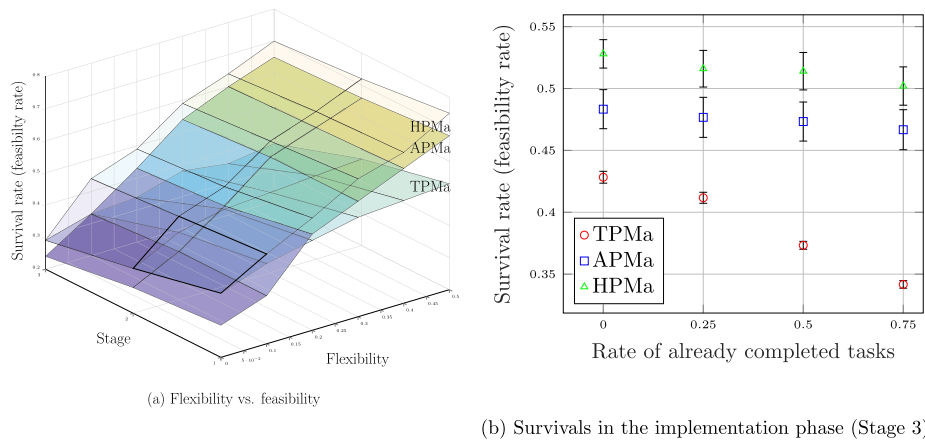


Fig. 7. Feasibility rate of project management agents by flexibility.

approaches, only the feasible project plans are surveyed. Fig. 7 shows that HPMa produced the most feasible projects. The agile approach is the second best in the case of a flexible project environment and the third best if there are a few possibilities to reorganize the project or postpone tasks. A similar figure can be drawn for the target functions, but if the remaining parameters are also considered that are not involved in the target function, we obtain a much more nuanced picture. In Fig. 8, the $TPX\%$ represents the scheduling performance for the target function. Moreover, $TPT\%$ shows the scheduling performance when the target function was not to reduce project durations. Similarly, $TPC\%$ shows the scheduling performance for cost when the target function was not to reduce costs. According to Eq. (3), higher values produce better performance, such as lower $TPT/TPC/TPR$, but higher TPQ and higher TPS . Fig. 8 shows that HPMa produces the best performance for targets ($TPX\%$) in all stages (83%, 81% and 75%), which means this approach secures the closest to the best total project value. However, the price of this approach is that other parameters are closer to the constraints. Furthermore, TPMa insists on scope; therefore, $TPS\%$ is always equal to 100%. However, the price of this requirement is that TPMa produces the longest projects, from which the risk effect endangers the customer's

and management's objectives, and the highest project budget is viewed as unfavorable to management, while the worst scheduling performance is achieved for targets in all stages (41%, 34%, and 14%). Nevertheless, TPMa demands fewer resources per time units, while parallelization of tasks in APMa and HPMa demanded more resources per time units; therefore, the restriction of the maximal amount of work-in-progress tasks is justified. Therefore, the price of utilizing flexibility is a more problematic resource management issue in agile/hybrid than in traditional approaches. This issue may be increased in a multiproject environment, where parallel projects should share resources with each other. APMa, while capable of maintaining the second place of the scheduling performance in all stages (71%, 64%, and 59%), usually achieved this performance with the shortest projects. It reached the lowest budget if other target functions were selected.

Performance of risk mitigation

Fig. 9 shows the performance of risk mitigation of the explored project management approaches. The ideal risk mitigation strategy maintains all project plans as feasible, while other $\Delta TPX_{2,1}\% = \Delta TPX_{3,2}\%$ values stay close to 1.

The TPMa keeps all tasks, and therefore, $\Delta TPS_{ij} = 1$ in all cases and

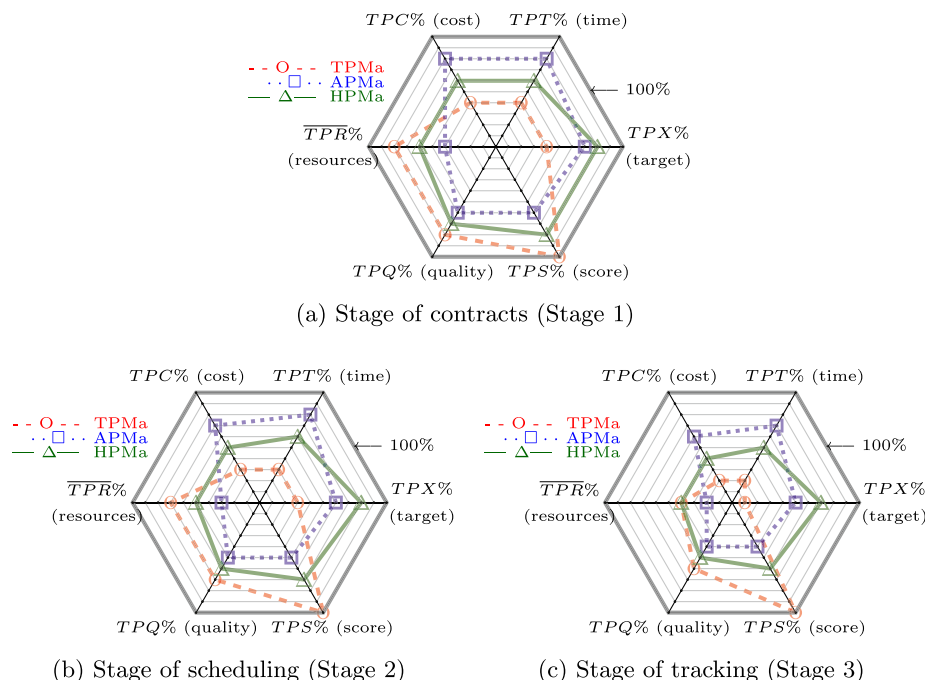


Fig. 8. Scheduling performance of targeted (TPX) and nontargeted (remaining) parameters.

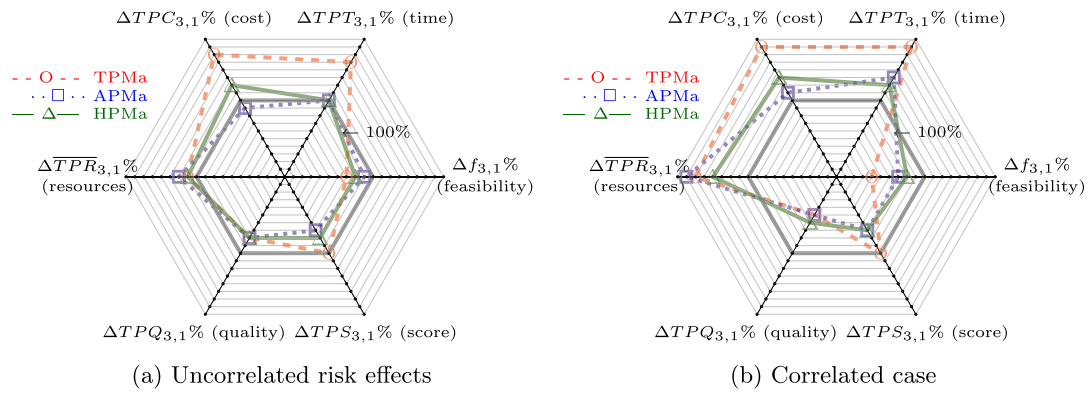


Fig. 9. Performance of risk mitigation of project management approaches.

for all $i > j$, but the price of this strategy is to "lose" more project plans than other strategies. Moreover, considering only feasible project plans, TPMa shows the greatest tendency to delays and overbudget situations. If risk factors are moderately correlated ($\rho \geq 0.6$), the TPMa demands a substantial amount of additional resources. The APMa shows a very different picture. Interestingly, the agile technique is the only approach that reduces project costs despite the risk factors. The price of this strategy, however, is that it attains the largest decrease in quality and scope. It is also interesting that when risk factors are moderately correlated, because of the forced parallelization, the demand for resources is increased to the greatest extent in this strategy. HPMa keeps most project plans feasible, and this approach creates balance within the

multimode methods and the restructuring techniques. Moreover, ΔTPX_{ij} is usually very close to one, which means that this strategy can well mitigate the risk effects in order to keep the project plans within the constraints. In the meantime, it retains more of the scope than agile techniques.

When risk factors are correlated with each other, they greatly enhance each other's risk effects. These effects of interdependencies between risk factors occur particularly in the case of using TPMa. TPMa is very sensitive to the changes in the time, cost and resource demands and their interdependencies, which is in line with the experience gained so far in software projects. The agile techniques can better mitigate the risk effects; however, if risk factors are correlated with each other,

Table 2
Summary table of results.

Project Management agents	TPMa				APMa				HPMa												
Assumptions																					
Multimodes									X												
Flexible dependencies																					
Feasibility	Rank	Stage 1			Stage 2			Stage 3			Rank	Stage 1			Stage 2			Stage 3			
$f\%$	3	0.48			0.43	0.34			2	0.50	0.48	0.47	1	0.58	0.53	0.50					
Risk effects																					
Uncorrelated case	Rank	$i = 2$			$i = 3$			Rank	$i = 2$			$i = 3$			Rank	$i = 2$			$i = 3$		
$\Delta f_{i-1}\%$	3				0.90	0.81			1	0.97	0.97	2					0.91	0.95			
$\Delta TPT_{i-1}\%$	3				1.19	1.31			2	1.04	1.02	1					1.02	1.03			
$\Delta TPC_{i-1}\%$	3				1.21	1.34			1	0.93	0.97	2					1.03	1.17			
$\Delta \overline{TPR}_{i-1}\%$	1				1.05	1.10			3	1.11	1.14	2					1.06	1.08			
$\Delta TPQ_{i-1}\%$	1				0.92	0.89			3	0.87	0.91	2					0.90	0.89			
$\Delta TPS_{i-1}\%$	1				1.00	1.00			3	0.88	0.90	2					0.93	0.91			
Correlated case ($r \geq 0.6$)	Rank	$i = 2$			$i = 3$			Rank	$i = 2$			$i = 3$			Rank	$i = 2$			$i = 3$		
$\Delta f_{i-1}\%$	3				0.68	0.61			2	0.84	0.91	1					0.94	0.93			
$\Delta TPT_{i-1}\%$	3				1.27	1.39			2	1.12	1.18	1					1.09	1.14			
$\Delta TPC_{i-1}\%$	3				1.28	1.37			1	1.01	1.10	2					1.14	1.17			
$\Delta \overline{TPR}_{i-1}\%$	2				1.22	1.31			3	1.24	1.37	1					1.20	1.19			
$\Delta TPQ_{i-1}\%$	1				0.81	0.71			3	0.77	0.70	2					0.78	0.80			
$\Delta TPS_{i-1}\%$	1				1.00	1.00			3	0.80	0.91	2					0.87	0.87			
Scheduling Performance	Rank	Stage 1			Stage 2			Stage 3			Rank	Stage 1			Stage 2			Stage 3			
For target functions ($TPX\%$)	3	0.41			0.34	0.14			2	0.71	0.64	0.59	1	0.83	0.81	0.75					
Remaining	Rank	Stage 1			Stage 2			Stage 3			Rank	Stage 1			Stage 2			Stage 3			
$TPT\%$	3	0.49			0.38	0.28			1	0.89	0.85	0.78	2	0.69	0.63	0.57					
$TPC\%$	3	0.41			0.31	0.21			1	0.81	0.76	0.69	2	0.63	0.53	0.47					
$\overline{TPR}\%$	1	0.85			0.74	0.44			3	0.41	0.37	0.27	2	0.61	0.51	0.40					
$TPQ\%$	1	0.82			0.72	0.61			3	0.62	0.52	0.42	2	0.72	0.62	0.57					
$TPS\%$	1	1.00			1.00	1.00			3	0.61	0.51	0.43	2	0.81	0.70	0.62					
Pros vs. cons for stakeholders:																					
Customer	Pros				Cons				Pros				Cons								
Management	High quality				Longest				Shortest				Lower quality								
Developers	Full scope				Lower feasibility				Higher cost				Less content								
	Lower res. dem. in time				Highest cost				Lower cost				Higher res. dem.								
	Lower res. dem. in time								Higher res. dem.				Best schedules								
													Highest feasibility								
													Highest feasibility								
													Best schedules								
													No multipurpose version								
													No multipurpose version								

because of the forced parallelization, this technique is also sensitive to the resources. Furthermore, agile, traditional and hybrid techniques may be useful to different stakeholders (see Table 2).

4.4. Importance of risk factors

The survival random forest algorithm is used to calculate variable importance (see Fig. 10). The projects that remained feasible at the end of the simulation stages were those that we considered as survived projects. Moreover, instead of time, the stages of the simulation and the scheduled rate of tasks are considered. Except for the target function ($p = .1017$), all variables are significant. The error rate of the model is only 0.0051.

Fig. 10 shows the effect of project management agents; all explored structural properties, such as project structure and flexibility; low-level risk factors, such as changes in costs (Δc), duration (Δt), resource demands (Δr), etc.; and high-level risks, i.e., when TPT, TPC, TPQ, or TPS values violate the corresponding constraint, that are assessed through the constraints ($C_s\%$). According to the result, the low-level root causes and structural parameters have a greater direct impact on survival. The most important variable for maintaining the project feasibility is the selected project management agent (XPMa, 24.3%). In addition, the second most important variable is the flexibility rate (18.8%), which was detailed in Section 4.2. The correlation between risk factors is more important (11.1%) than the risk factors themselves; therefore, a meta-analysis to consider the interdependencies between risk factors is justified. The effect of correlation between risk factors is detailed in Section 4.3. The selection parameter (shock effect, $\Delta p \in 0.1, 1.0$) is the fourth important variable (8.8%). According to the results, TPMa is the most sensitive to the shocks ($\Delta p = 0.1$), where only a few (i.e., 10%) of task demands are changed, but these changes are (even 10 times) higher.

The risk factors ($\Delta r, \dots, \Delta t$) are more important than the constraints as the result of an agreement ($C_t\%, \dots, C_r\%$). This observation proves that after the contract phase, there are more challenges for the project manager to ensure that the project plan remains feasible. The more challenging task is the resource allocation, both in the traditional and in the flexible project management approaches (see the details in Section 4.3).

The database contained not only IT but also a construction project; therefore, it is an interesting result that the original project structure, regarding the size (number of tasks, n (1.2%)) and i_2 , which shows the parallelization, is less important (1.5%). The importance of the data source (simulation or real project) also has low importance (1.9%). The low importance value of the result raises the possibility that flexible

approaches can be successful in different kinds of project structures, and if the technology were to allow these approaches, they could also be successful in non-IT projects. This result is explained by the fact that flexible techniques also allow parallelization when they can reorganize the project structure. Therefore, the main question regarding the use of the flexible project management approach, such as agile and hybrid approaches, concerns whether the project plan is considered flexible. Alternatively, in other words, to use flexible project management approaches, the project plans must be flexible. Whether it is an IT or a non-IT project is of secondary concern.

4.5. Threats to validity

Internal validity threats can affect the independent variable with respect to causality. To avoid such a threat, the following actions were taken:

- **Exploring multiple groups:** IT-projects and non-IT-projects were separated into two groups. Nevertheless, the homogeneity of project structures are explored (see Section 4.1). The selection of project structures was based on former studies [see, e.g., 63]. Selection criteria are applied; see Section 3.1. However, a new project database should contain quality and score values for testing flexible approaches.
- **Treating missing variables:** Although quality and score values were missing from every dataset, they have been generated according to former studies; see Section 3.1.

The external validity involves the possibility of generalization of results outside the scope of experimental settings. To improve external validity, we include a real-life project database. In addition to standard (see Dataset A in Section 3.2) and generated (see Dataset B in Section 3.2) datasets, a real-life dataset Dataset C is considered for the simulation. Further project structures can be investigated if the required parameters exist and/or can be calculated/simulated. Since the dependency and flexibility scores cannot be observed in real examples or obtained from standard databases, the survival ratio of the projects can change, but the effect of the flexibility can be studied due to the wide range of the flexibility ratio.

Construct validity threats may be due to the simplifications made in the software project process modeled for the optimization and the inappropriate application of simulation. To mitigate the effects of such threats, the following actions were taken.

- **Applied exact methods:** Agents are based on exact methods, which guarantee optimal solutions. Therefore, not only the feasibility but also the scheduling performance can be explored.
- **Applied distributions:** Variables (risk factors) in the sensitivity analysis that are based on Monte Carlo simulations followed the β -distribution, which is used in practice (see Section 3.4).

To ensure construct validity of the risk evaluation tool (SABRE), the following was performed.

- We used state-of-the-art techniques, e.g., pair programming and code reviews and followed current best practices throughout the implementation, such as optimization of hyperparameters of RFS.
- Thorough white-box testing for verification (including external libraries) was performed.
- Moreover, the work group of the study includes practicing PMs and engineers with many years of relevant experience in software engineering and project management disciplines.

To improve the conclusion validity, we applied RFS, which is a very robust method and quasi-independent from the interdependence of the risk factors. In addition, this method handles different (discrete or

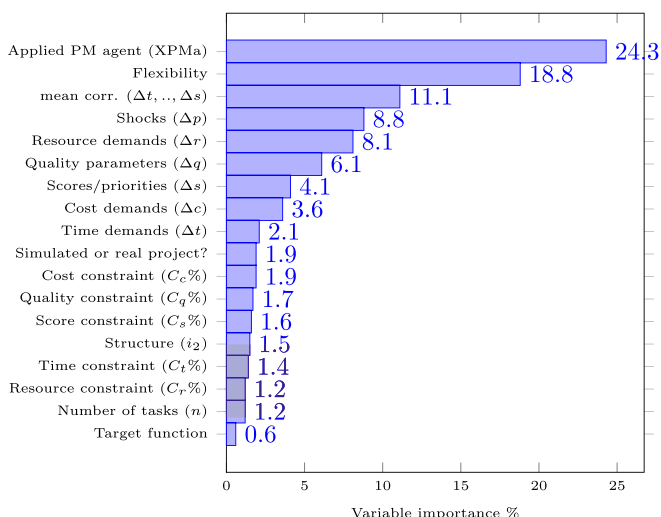


Fig. 10. Variable importance for survivals.

continuous) scales of risk factors. The large-scale simulation ensured that the only variables that were insignificant were those that had no influence on survival. Nevertheless, with this distribution, the risk effects can be underestimated if the range of the distribution is narrow. Therefore, we applied a wide range (40% of the most likely value) (see Section 3.4.2).

5. Summary and conclusion

The proposed paper considers recent agile and hybrid project scheduling techniques and compares them to the traditional project management approaches in order to explore which method produces the highest amount/ratio of survived projects (RQ_1), which method mitigates the risk effects the most (RQ_2) and which project (management) properties and risk factors are the most important for scheduling performance and risk mitigation (RQ_3).

In terms of scheduling, the traditional project management approach and the implemented TPMa operate only in terms of multimodes of task completion. This approach assumes that tasks can be completed in different kinds of ways. In contrast, agile techniques assume a flexible project structure, where dependencies between tasks can be flexible and lower-priority tasks can be postponed until the next project, but usually, only one completion mode is specified. The results showed that in the case of a flexible project environment, where the flexibility rate is high, this approach can truly produce more feasibility, and in this way, it can make remarkably more projects capable of success than traditional approaches. However, this advantage dissipates when the technology requires strict dependencies.

Hybrid techniques allow both multimodes and the flexible structure, and therefore, it is assumed that this is the supreme technique of project management. This assumption is reinforced by the fact that this technique provides the highest ratio of feasible solutions and the best scheduling performance when we consider only the target function (see Table 2). To answer RQ_1, based on the proposed database, HPMa provides the most of the feasible solutions; therefore, **a software development project is more likely to survive the risk effects if a project plan is managed by a hybrid project management approach.**

Currently, the flexible project scheduling algorithms are much less sophisticated than the trade-off methods or the MRCPSp algorithms. For example, there is currently no multipurpose version of agile or hybrid scheduling, and only one target is considered in scheduling and risk mitigation. Table 2 shows the ranks in addition to the scheduling and risk mitigation values. The results show that the HPMa does not usually mitigate the risk effects the best (see RQ_2). Nevertheless, selecting an adequate project management approach and ensuring the project flexibility (see Fig. 10) are the main factors for both feasibility, and performance of scheduling and mitigation. Notwithstanding these findings, because of technical requirements, there are substantially more obligatory dependencies between tasks, and the flexible project management approaches do not achieve better performance.

Nevertheless, to answer RQ_3, the most important variable for project survival is to select an adequate project management agent, but the second most important variable is ensuring flexibility. The flexibility parameter is much more important than the other structural parameters, such as the project size or the number of work-in-progress (WIP) activities, which are very limited in flexibility, especially in agile project management approaches.

5.1. Implication for practitioners

The proposed paper compares traditional, agile and hybrid project management approaches in view of different kinds of stakeholders. The paper proposes a meta-network analysis method, which has not been applied in software development projects to date. The analysis showed that all methods not only have advantages but also have disadvantages. Most of them are in line with experience, but other methods need a

deeper analysis. First, similar to experience, traditional project management approaches produced the most infeasible project plans. This result completely matches the Chaos Report's results [56], where waterfall projects, which follow traditional project management approaches, provided three times more failed projects. However, this study also demonstrated that a benefit would occur only if at least 20% of tasks and dependencies were flexible (see Fig. 7). The lesson we learned is that when this requirement cannot be satisfied, the agile project management approach can produce more failed (i.e., infeasible) projects. Due to the project flexibility, the other impressive result is that an agile project management approach usually obtains the shortest and least expensive projects, even though specifying a single implementation mode. However, the expense of this strategy is less content and lower quality. For this reason, it is indeed essential to involve customers for whom the scope of activities to be excluded from the project should be defined (see Table 2). At the same time, it is also a vast challenge for developers to manage many parallel activities simultaneously. The hybrid project management approach can take advantage of both flexibility and the choice of completion modes for scheduling; therefore, it provides the best schedules and those that are most feasible, and after the risk analysis, those with the most survived project plans, but these values are best only for the target functions.

The study showed that the most important factor for the survival of a project plan is to select an adequate project management approach. The hybrid and, especially, the APMas are better in the flexible project environment. In this case, more feasible and better (i.e., shorter, less expensive, etc.) projects can be specified. Nevertheless, the project structure, such as the size and the parallelization (i_2), are less important factors for survival. Currently, flexible approaches are also used in many non-IT projects. Our results showed that the flexible nature of the project rather than the project's specific structure can increase the success of the project or mitigate the risks more. The paper showed that extended meta-network analysis can be used for exploring the effects of flexibility. Agile and traditional project management approaches can usually better mitigate the effects of risk factors, while the hybrid approach helps to ensure the most surviving projects.

5.2. Implication for scholars

The proposed multi-layer network analysis and survival analysis-based risk evaluation (SABRE) tool showed that these techniques can be used not only in construction projects but also in software development projects. With SABRE, the study showed that agile and traditional project management approaches are more sensitive if risk factors are correlated with each other (see Table 2). The proposed simulation model can investigate the impact of formerly not or hardly studied risk factors, such as project structures, shocks and flexibility. In addition, with the proposed model, scholars can dynamically tune the level of flexibility in hybrid and agile approaches. The authors believe that great potential lies in the meta-network structure. Further kinds of risk factors and their interdependencies can be easily added to the existing networks to enhance simulation models.

The study also highlighted an important shortcoming of agile and hybrid approaches, namely, that they have no multipurpose version that can balance the different kinds of goals of stakeholders.

Another possible extension of the proposed model, as yet hardly studied, is to examine flexible multilevel project risk managements, where risks effects of simultaneous projects may also impact each other.

6. Limitations

This study compared existing scheduling methods in a proposed risk evaluation framework (SABRE). Since there is no multipurpose version of agile and hybrid project scheduling, only one target function is considered at one time. Only single projects are considered; however, the relatively fast scheduling algorithms allow us, in a following paper,

to compare these approaches in a multiproject environment, where they have to share their resources among the projects.

The SABRE tool is not for identification of all possible risk factors but rather for an evaluation of those that stem from a combination of the applied management approach, the project structure, the uncertainty of estimating the (time, cost, resource) demands of the activities, the vaguely defined or changing customer requirements, or the appearance of unexpected events (shocks). While the tool provides a sensitivity analysis and ranks the effects, helps to prioritize the countermeasures, and shows which approach gives the best results for the objective function, it does not suggest any additional mitigation techniques.

The lack of scores and quality values of task completions in the applied project database does not understate the importance of specifying prioritization and quality issues and requiring these steps for planning and managing flexible projects; therefore, project databases should be extended to include these values for further investigations.

CRedit authorship contribution statement

Zsolt T. Kosztyán: Conceptualization, Methodology, Funding acquisition, Formal analysis, Writing - original draft, Writing - review & editing. **Róbert Jakab:** Conceptualization, Methodology, Funding acquisition, Formal analysis, Writing - original draft, Writing - review & editing. **Gergely Novák:** Conceptualization, Methodology, Funding acquisition, Formal analysis, Writing - original draft, Writing - review & editing. **Csaba Hegedűs:** Conceptualization, Methodology, Funding acquisition, Formal analysis, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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