THESIS SUMMARY

Matrix-based project planning method for multi-level project environments

Author:
Gergely Lajos NOVÁK

Supervisor:
Prof. Dr. habil. Zsolt Tibor KOSZTYÁN

UNIVERSITY OF PANNONIA

Doctoral School in Management Sciences and Business Administration
Department of Quantitative Methods

April 6, 2023

1 Introduction

Our society is substantially projectified (Godenhjelm et al., 2015). Around 40% of the global economy is project-based and project management is a fundamental process for producing products and services (Turner et al., 2010). Projects of all types can contribute almost 20% of a country's GDP (Denizer et al., 2013; World Bank, 2012), and have become the standard way of doing business.

To cope with the dynamic business environment and the increased complexity of products and services (Hobday, 2000), 84% of companies run projects simultaneously (Lova et al., 2000) and a similarly high percentage was reported already in the nineties (Payne, 1995). With a slow shift from the long-standing single project management paradigm, the challenges of these multiproject environments are still prevailing.

Several studies have shown that to increase the success of today's projects (Johnson, 2020), where uncertainties are inherent (Hazır and Ulusoy, 2020) and the work is intensified and compressed (Söderlund, 2005), traditional project management approaches are increasingly being replaced by flexible approaches (Ciric et al., 2019; Hidalgo, 2019; Özkan and Mishra, 2019; Wysocki, 2019) not only in the IT field (Stare, 2014) but also previously unconsidered fields, such as construction (Yasaman et al., 2022) and maintenance projects (Kosztyán, Pribojszki-Németh, et al., 2019). The need to apply new methodologies generated numerous research challenges and the importance of project planning and scheduling has remained unchanged (Serrador, 2013), yet flexible approaches are narrowly studied (Pellerin and Perrier, 2019).

These emerging approaches require flexible project plans, allowing, for example, the possibility of either or both project restructuring and task reprioritization according to the customer's requirements; however, most project planning methods assume a fixed logic plan (Franco-Duran and Garza, 2019) or a limited number of scheduling alternatives (Čapek et al., 2012; Creemers et al., 2015; Hauder et al., 2020; Kellenbrink and Helber, 2015; Servranckx and Vanhoucke, 2019; Tao and Dong, 2018). There are already a few matrix-based methods available for scheduling structurally flexible projects and multilevel projects (Kosztyán, 2015; Kosztyán and Szalkai, 2020) where certain task realizations and dependency occurrences are considered as variables during the planning phase.

However, there is neither a project database that supports the design, planning, and scheduling of flexible (multi)projects nor a set of complexity and time- or resource-related indicators that are capable of characterizing flexible project plans available. Despite that project data has become a fundamental part of the research, still, a significant amount of existing project databases are often inaccessible, heterogeneous in terms of formats and attributes, and lack standardization. It is thus essential to provide both scholars and practitioners with standardized databases and a set of indicators to allow them to examine flexible projects.

Therefore, the aim of the dissertation was fourfold:

✓ To specify a matrix-based method, which can handle

[+] single and multi-level projects,

[+] multiple execution modes,

[+] flexible projects besides traditional ones.

✓ To collect existing heterogeneous project databases, including:

[+] simulated (artificial),

[+] real-life projects.

✓ To examine the effects of flexibility not only on the project structure but on the project demands as well.

✓ To provide a framework for effective planning of flexible (multi)project plans.

2 Research questions

Considering the relevance and goals above, the current study seeks to answer the following research questions:

RQ1: How to create a unified model that can represent the heterogeneous project and multiproject databases available in the literature?

RQ2: How the flexibility of single- and multiproject plans can be modeled?

RQ3: What characterizes the topology (structure) and the different demands of the flexible project and multiproject plans?

RQ4: How is it possible to find feasible (sub)optimal solution for the single- and multiproject plans considering flexibility?

3 Related studies and research assumptions

Flexible multi-level project management and matrix-based scheduling

Agile project management has already gained popularity outside of software development context (Bergmann and Karwowski, 2018; Bianchi et al., 2018; Conforto et al., 2014; Owen et al., 2006) and adapts to uncertainty and changes even in later phases of a project. It focuses on prioritized items and requirements that offer the most business value in time, while traditional project management tries to predict and minimize change (Ciric et al., 2019) and emphasizes formal methods of planning. In a multilevel project environment, multi-projects, programs, and portfolios need to be scheduled. The projects vary in size, importance, required skills, and urgency, are in various stages of completion, and use the same pool of resources (Fricke and Shenbar, 2000). The management of multilevel projects presents a significant challenge that is fundamentally different from single project management (MacAskill and Guthrie, 2017).

Traditional network-based project planning tools (see e.g., Eisner, 1962; Kelley Jr, 1961; Roy, 1962; Wiest, 1981) are no longer able to fully support the strategic decisions of companies (Kosztyán, 2012). The few scheduling algorithms that address multilevel projects follow the traditional scheduling methodology, where the activities have a fixed order of execution (Pellerin and Perrier, 2019). Matrix-based project planning can eliminate the shortcomings of traditional methods; it is possible to plan agile and hybrid projects as well as traditional projects. The matrix-based project planning methods are often based on the design (or dependency) structure matrix (DSM) (Kosztyán, 2015; Steward, 1981). The domain mapping matrix (DMM) is an extended version of the DSM but with multiple domains (Danilovic and Browning, 2007). Kosztyán (2015) suggested a project domain matrix (PDM), that can be used for both single and multimodal project plans. PDMs allow mandatory and supplementary tasks with priorities and flexible dependencies between tasks. Kosztyán (2020) later extended this matrix-based model to address multiple projects, programs and project portfolios. This matrix-based multiple project management model is denoted M^4.

Resource-constrained (multi)project scheduling problem

The classical resource-constrained project scheduling problem (RCPSP) consists of a set of activities that need to be scheduled, subject to precedence and resource constraints, to optimize an objective function, e.g., minimizing the overall duration of a project. Both exact and heuristic solutions and various extensions have been investigated. Hartmann and Briskorn (2021) provides an overview and classification of the most important extensions of the RCPSP.

An important extension, the resource-constrained multiproject scheduling problem (RCMPSP), deals with multiple projects using the same resources that must be scheduled without violating the resource constraints. For a survey of the different RCMPSP extensions, see Hartmann and Briskorn (2021), Issa and Tu (2020), and Van Eynde and Vanhoucke (2020). A comprehensive, state-of-the-art survey of the different methods, variants, features, and objectives are also given in (Sánchez et al., 2022).

Flexibility of projects

Broadly defined, flexibility is the magnitude of the room for scheduling decisions (for an overview of the different definitions, see Bernardes and Hanna, 2009). (Multi) project scheduling is open to several flexibility types; time-related or scheduling flexibility can result from slacks or topological floats (see Tavares (1999) and Vanhoucke, Coelho, Debels, et al. (2008)), also in traditional project plans.

The second type is activity (i.e., task) or modal flexibility in which a task can be performed in several execution modes having different demands. Čapek et al. (2012), Kellenbrink and Helber (2015), and Tao and Dong (2018) defined RCP(M)SP with alternative activity chains resulting in RC(M)PSP-AC problems, while Hauder et al. (2020) extended it with time-related flexibility (RCMPSP–ACTF).

The third type is dependency flexibility. Some logical dependencies can be omitted if the project task technology does not require a strict sequence. Omitting a dependency lifts the restriction of sequential execution and allows the associated tasks to be performed in parallel or in an arbitrary, relative order.

The fourth type is scope flexibility, in which some low-priority tasks can be omitted or postponed to a later project. The latter two flexibility types appear typically, but not exclusively in agile projects (Kosztyán, 2015) and affect the logical structure of a project. Dependency and scope flexibility are together called structural flexibility, also examined within this study.

Project databases

Project databases play a key role in the research of different scheduling and resource allocation methods (Brucker et al., 1999; Hartmann and Briskorn, 2010, 2021) by making them comparable and developing new methods (Franco-Duran and Garza, 2019). Individual projects are available in various databases, such as Patterson (Patterson, 1976), SMCP and SMFF (Kolisch et al., 1995), PSPLIB (Sprecher and Kolisch, 1996), RG300 and RG30 (Debels and Vanhoucke, 2007; Vanhoucke, Coelho, Debels, et al., 2008), Boctor (Boctor, 1993), MMLIB (Peteghem and Vanhoucke, 2014), the real-life project database by (Batselier and Vanhoucke, 2015), or sets of individual or multiple projects, including MPSPLIB (Homberger, 2007), BY (Browning and Yassine, 2010a), RCMPSPLIB (Vázquez et al., 2015), and MPLIB (Van Eynde and Vanhoucke, 2020).

Project related indicators

Project related indicators can be used to classify existing project plans based on different characteristics and as input parameters for the random generation of artificial project plans. The indicators for project plans can be classified into two main groups. The first group characterizes the project structure, including measures of its complexity, and the second group characterizes the project demands, such as resource, time, and cost. There are several indicators proposed in the literature. A general overview of indicators and databases is given by Vanhoucke, Coelho, and Batselier (2016). For multiprojects, Browning and Yassine (2010b) gives an overview of the existing indicators, which was extended by Van Eynde and Vanhoucke (2020) recently, showing the relevance and interest for the research of different indicators.

3.1 Research assumptions

By revisiting the research questions after reviewing the literature, it becomes possible to formulate the corresponding research assumptions. The four research assumptions are as follows:

RA1: A model can be created that unifies the different project and multiproject database formats from the literature, including time, cost, renewable-, nonrenewable-resource and quality demands. Existing databases can be imported and further extended with flexible tasks and dependencies into a single, matrix-based database.

RA2: Flexible project plans can be generated from existing traditional (multi)project plans and new possible structures can be added to the model to improve the planning process.

RA3: Existing project-related indicators for topology, time- and resource-related demands can be adapted for flexible projects and multiprojects to analyze the effects of flexibility.

RA4: Flexible multilevel projects can be scheduled and near-optimal solutions can be found. A simulation framework can be constructed to handle flexible dependencies and supplementary tasks.

4 Results and research theses

RQ1: *How to create a unified model that can represent the heterogeneous project and multiproject databases available in the literature?*

To unify the heterogeneous project databases, a matrix-based model is proposed based on the M^4 model by Kosztyán (2015, 2020), called the *unified matrix-based project-planning model* (UMP). It contains two mandatory (LD, TD) and four supplementary domains (marked with dashed lines) as shown in Figure 1.

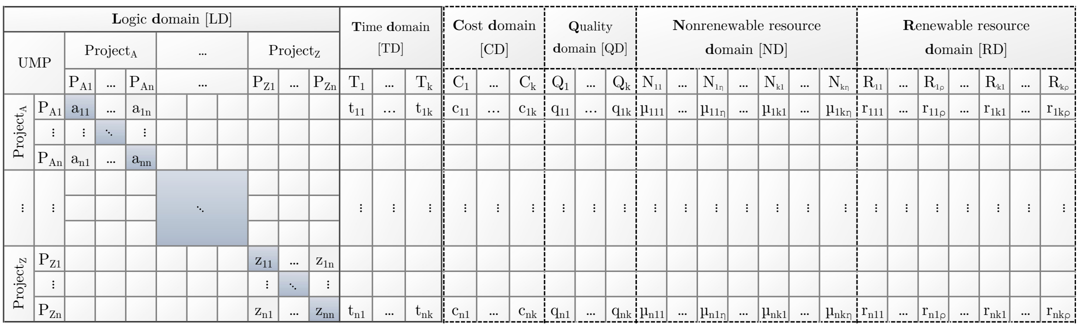


FIGURE 1: Structure of the unified matrix-based project-planning model (UMP)

LD The logic domain is an n by n matrix, where n is the number of tasks. Each cell contains a value from the [0,1] interval.

TD The time domain is an n by k matrix with positive real values, where k is the number of completion modes.

The first mandatory domain is the logic domain, $\mathbf{LD} \in [0,1]^{n \times n}$. The diagonal values in **LD** represent the task priority values. If a diagonal value is 0, the task will not be completed, and if the diagonal value is 1, the task is mandatory. If the diagonal value is between 0 and 1, the task is supplementary, indicating that depending on the decision, it will be either completed or omitted/postponed.

The out-diagonal values represent the dependencies between the tasks. If an out-diagonal value $a_{ij} = l_{ij} = [\mathbf{LD}]_{ij}$ $(i \neq j)$ is 1, task i precedes task j. In the case of $l_{ij} = 0$, no precedence relation exists from task i to task j. If $0 < l_{ij} < 1$, a flexible dependency exists between task i and task j, indicating that task i may precede or follow task j depending on managers' (algorithm) decisions. All flexible techniques, such as agile, hybrid, or extreme, require flexible dependencies between tasks (Ciriello et al., 2022; Fernandez and Fernandez, 2008).

The other mandatory UMP domain is the time-related domain. The positive values of the time domains represent the possible task durations. For each task, k kinds of durations can be assigned; the duration values may also match each other.

The additional supplementary domains are as follows:

CD The cost domain, is an n by k nonnegative matrix of the task costs

QD The quality domain, is an n by k, nonnegative matrix of the task quality parameters, where the quality parameters are between [0,1]

ND The nonrenewable resource domain, is an n by $k \cdot \eta$ nonnegative matrix of nonrenewable resource demands, where η is the number of types of nonrenewable resources

RD The renewable resource domain, is an n by $k \cdot \rho$ nonnegative matrix of renewable resource demands, where ρ is the number of types of renewable resources

The project databases collected were heterogeneous both in terms of format and attributes. Building a parser tool for the current study in MATLAB (Mathworks, 2021), and using the UMP, it was possible to unify the databases summarized in Table 1. The corresponding **RA1** is thus accepted.

TABLE 1: Selected project databases and their attributes
Source: own edit

Name	Project Plan	Completion Modes	Projects	Demands	Cited as
Patterson	Generated	Single	Single	Time, renewable resources	Patterson, 1976
PSPLIB	Generated	Single, Multiple	Single	Time, re/nonrenewable resources	Sprecher and Kolisch, 1996
RG30, RG300	Generated	Single	Single	Time, renewable resources	Vanhoucke, Coelho, Debels, et al., 2008
SMCP, SMFF	Generated	Single	Single	Time, renewable resources	Kolisch et al., 1995
Boctor	Generated	Multiple	Single	Time, renewable resources	Boctor, 1993
MMLIB	Generated	Multiple	Single	Time, re/nonrenewable resources	Peteghem and Vanhoucke, 2014
Real-life	Collected	Single	Single	Time, cost, renewable resources	Batselier and Vanhoucke, 2015
MPSPLIB	Generated	Single	Multiple	Time, renewable resources	Homberger, 2007
BY	Generated	Single	Multiple	Time, cost, renewable resources	Browning and Yassine, 2010a
RCMPSPLIB	Generated	Single	Multiple	Time, renewable resources	Vázquez et al., 2015
MPLIB1, MPLIB2	Generated	Single	Multiple	Time, renewable resources	Van Eynde and Vanhoucke, 2020

RQ2: *How the flexibility of single- and multiproject plans can be modeled?*

Since none of the project databases considers flexible project structures, these are generated from fixed structures. According to the specified flexibility parameter ($fp \in [0,1]$), the rate of mandatory tasks and fixed dependencies are converted by the flexible structure generator (FSG). Specified by the ratio fp, the values of cells containing 1s decreased from 1 in between 0 and 1. In this way, the rate of supplementary tasks and flexible dependencies can be set. When the supplementary tasks and all flexible dependencies are excluded from (included), projects (Kosztyán, 2015) are called *minimal (maximal) project structures*, denoted $\mathcal{S}_{\min}$ ($\mathcal{S}_{\max}$), see the example in Figure 2.

In the case of an early schedule, the maximal (minimal) resource use occurs when all supplementary tasks are included in (excluded from) the project while all flexible dependencies are excluded from (included in) the project structure. These structures are henceforth called *maximin (minimax) project structures* denoted $\mathcal{S}_{\text{maximin}}$ ($\mathcal{S}_{\text{minimax}}$) (see the left side of Figure 2).

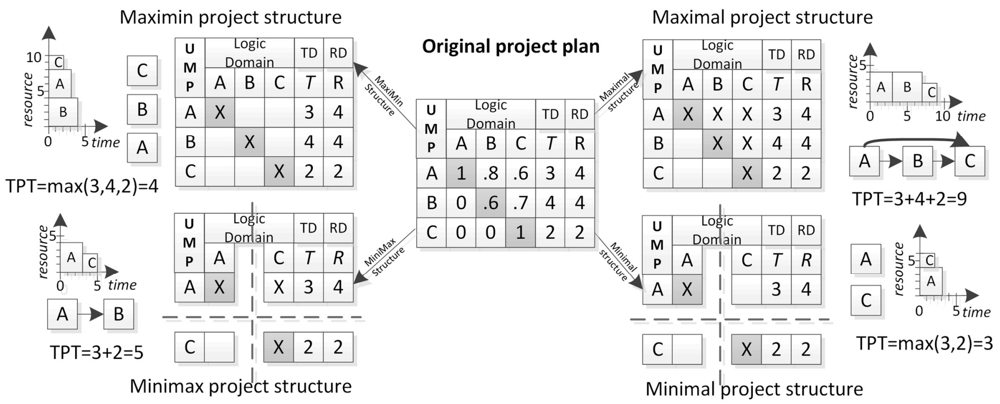


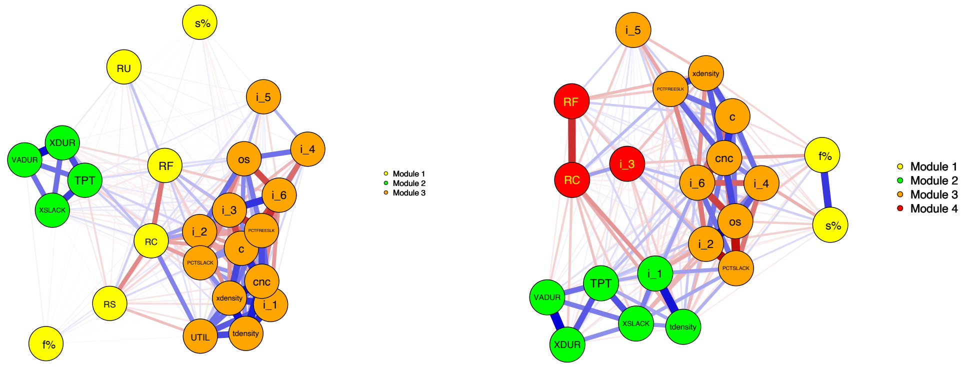
FIGURE 2: Minimal, maximal, minimax and maximin structures of the flexible project plan

To indicate that the minimal, maximal, minimax and maximin structures are the results of a decision, the mandatory tasks and fixed dependencies are represented by X, while the omitted tasks and independence are represented by empty cells.

After flexibility is set, the minimal, maximal (which is the original structure in this case), minimax and maximin structures can be added to the compound matrix-based project database (CMPD) database for further evaluation and to improve planning. As a result, **RA2** is accepted.

RQ3: *What characterizes the topology (structure) and the different demands of the flexible project and multiproject plans?*

Using project related indicators on the fixed structures, with clustered correlation graphs and Leiden's modularity (Traag et al., 2019), the modules of indicators were formed. Figure 3 shows the clustered correlation graph between the indicators in the single-project database. In the center of the modules are the indicators that correlate with most other indicators. On the periphery are the indicators correlated with relatively few other indicators, and their correlations with the remaining indicators are weak.



(a) For the simulated projects

(b) For the real-life database ($RS, UTIL$ cannot be used in correlation graph)

FIGURE 3: Clustered correlation graph between the indicators[1]. Notes: The correlation strengths are proportional to the tightness of the arcs between the nodes. The blue (red) arcs indicate positive (negative) correlations.

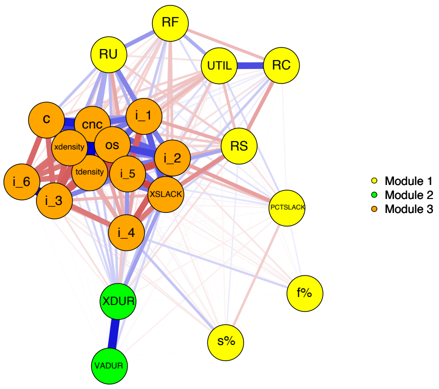
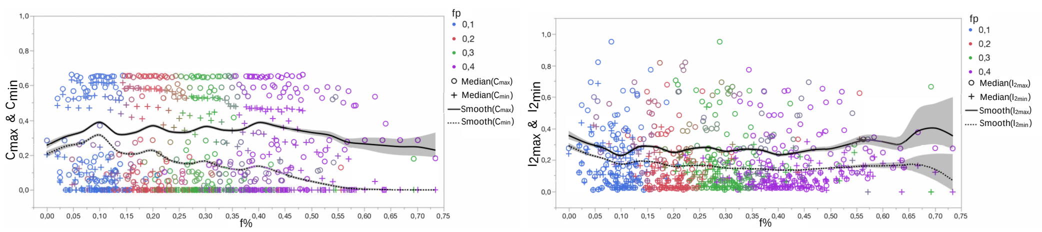


FIGURE 4: Clustered correlation graph of the multiple project database indicators. Note: indicators represent average values.

Figure 3 shows that several redundant indicators were highly correlating, especially the topological indicators (Module 3). In comparison, the proposed ($s\%, f\%$) flexibility indicators were located on the periphery (Module 2), so they need not to be merged. The modules in the simulated datasets were quite well provided with the structure-related, time-related and resource-related indicators, where the complexity (C), resource constrainedness (RC), and project duration (TPT) played central roles. At the same time, the real-life dataset provided more mixed modules. More significant differences can be seen between the simulated vs. real-life indicators than between the single vs. multiple project indicators. The multiple project database also produced three modules.

Flexibility considerations not only expand the interval of the indicator values but also specify new value pairs for the coupled indicators. The interpretation ranges of the indicators of multiprojects are also broadened.
Regarding project topology, Figure 5 compares the complexity (C) and parallelization (I_2) indicator values of the minimal and maximal structures regarding the ratio of flexible dependencies ($f\%$) (marked on the horizontal axis).



(a) Flexibility vs complexity

(b) Flexibility vs parallelization

FIGURE 5: Structural changes in complexity and parallelization

Figure 5 shows that when the flexibility parameter (fp) was increased via an increase in the rate of flexibility dependencies ($f\%$) for the minimal structures, the complexity (C) decreased (see Figure 5(a)), as did the serial completions (see Figure

5(b)). These results are in line with the requirements of flexible project management approaches for reducing project complexity (Williams, 2010).

Figure 6 shows the pairs of the indicator values of the total slack ratio (TOTSLACK-R) and average slack ratio (XSLACK-R) as time-related indicators on the vertical axis and structural parameters on the horizontal axis.

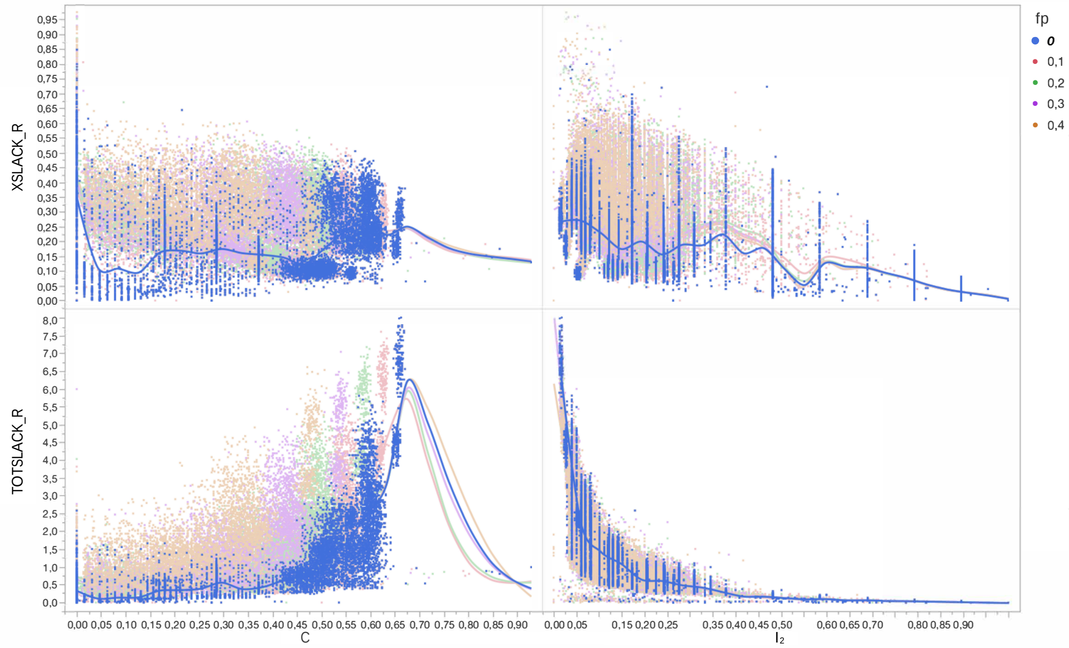


FIGURE 6: Flexibility effects on the relations between the time-related and complexity indicators

Figure 7 shows the relations between time- and resource-related indicators for the earliest start schedule. Considering the minimal structures of flexible projects, the resource constrainedness, and the obstruction factor are increased. These combinations of time-related and resource-related indicator values occurred only in flexible project plans.

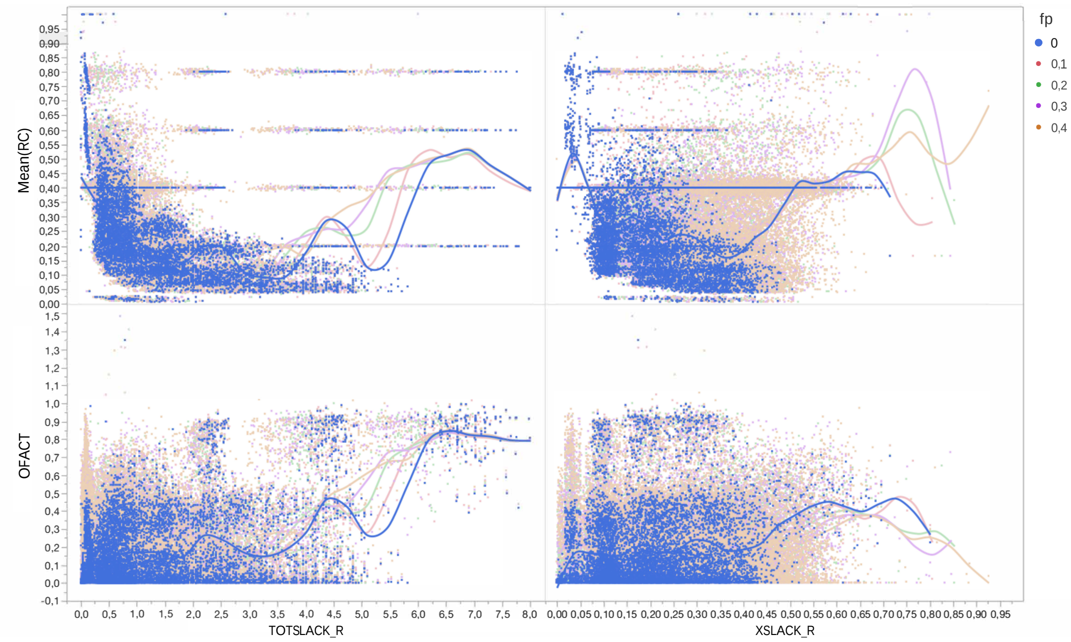


FIGURE 7: Flexibility effects on the relations between the time-related and the resource-related indicators

To analyse how flexible methods affect total project times (TPT) compared to traditional methods in the available groups of databases, the variances were calculated for each flexible case (represented by $fp = \{0.1, 0.2, 0.3, 0.4\}$) relative to the traditional methods (represented by $fp = 0$) within each group. The coefficient of variation (CV) then used to show the extent of variability in relation to the mean of the population.

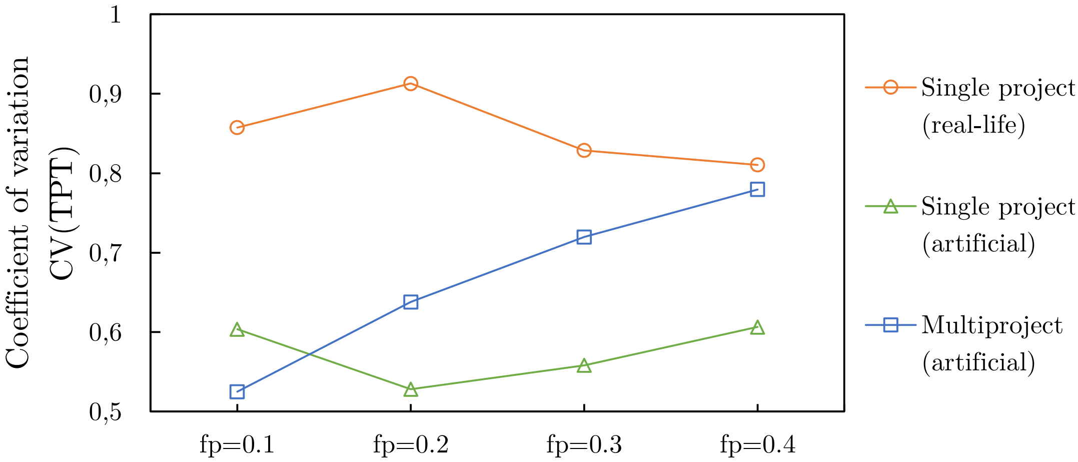


FIGURE 8: The coefficient of variations of average total project time by flexibility parameters of different database groups

As Figure 8 shows, artificial multiproject databases have the lowest initial variation for average total project time and it is similar to artificial single projects. Real-life single projects have a relatively high initial variation compared to artificial single and multiprojects. The shape of single projects (both artificial and real-life) seems inconclusive, while the variation of multiprojects average total project time is continuously increasing, which suggests that their durations are less predictable and hard to plan with. A regression model was also built to model the relationship between flexibility and multiproject durations besides existing descriptive statistics. Based on the evaluation of the different effects of flexibility, **RA3** is accepted.

RQ4: *How is it possible to find feasible (sub)optimal solution for the single- and multiproject plans considering flexibility?*

To demonstrate that the flexible project plans (generated by FSG) can be solved to (near) optimality with existing algorithms, the NP-hard (Lenstra and Rinnooy Kan, 1978) resource-constrained multiproject scheduling problem (Pritsker et al., 1969) needed to be solved.

In the presented case study, an empirical multiproject plan was selected for this purpose. Due to the complex nature of the RCMPSP problems and a large number of activities with high resource-constrainedness, this study considered a metaheuristic optimization in line with the literature (Pellerin, Perrier, and Berthaut, 2020) to achieve near-optimal solutions. The commercial optimization engine OptQuest™ was used within the simulation framework developed as part of the current study.

From the flexible multiproject plan the fixed structures were generated. The optimization was carried out with the objective to minimize the average total duration of multiproject, respecting the resource constraints. The average duration of the maximal (original) structure have increased with 0.5% to respect (the originally violated) resource constraints, suggesting that the company's plan was rather optimistic. The maximin structure reduced the average multiproject duration with 5.14%, the minimax reduces approximately 24.77% and a 31.31% reduction could be achieved using the minimal structures, as summarized in Table 2. It was possible to find near-optimal solutions for all newly specified structures, which validates **RA4**.

TABLE 2: Results for scheduling possible structures of the software development multiproject

Structure	Projects	Tasks	Dependencies	Res. constraints α_1, α_2	$\overline{TPT}_{EST}$	$\overline{TPT}_{OPT}$	$TPT_{EST}^{portfolio}$	$TPT_{OPT}^{portfolio}$
Maximal	5	150	49	55; 45	213	214*	413	413*
Maximin	5	150	38	55; 45	157	203*	357	390*
Minimax	5	100	28	55; 45	147	161*	347	361*
Minimal	5	100	22	55; 45	115	147*	315	338*

Note: **resource-feasible solution*

5 Research theses

Considering the research questions and assumptions with the corresponding results, four research theses were formulated.

RT1: [Model] The proposed unified matrix-based project-planning model (UMP) can represent both traditional and flexible single project, multiproject, and program plans. It addresses the demands of renewable and non-renewable resources, time, cost, and quality with single and multiple execution modes.

RT2: [Structures] The flexible structure generator (FSG), is able to specify possible minimal, minimax, maximin, and maximal matrix-based structures corresponding to a defined flexibility parameter, which can be added to the model. The planning phase of projects is improved by considering these additional outcomes with their demands.

RT3: [Indicators] There is a relationship between the modeled flexibility and topology, time-, and resource-related indicators.

> **RT3.1:** [Topology] With an increased rate of flexibility, structural indicators show reduced complexity and reduced serial completions (higher parallelity) for minimal structures.
>
> **RT3.2:** [Time] As the rate of flexibility increases, time-related indicators show decreased project duration and increased average slack ratio.
>
> **RT3.3:** [Resources] With increased flexibility ratio, resource-related indicators show higher average resource utilization and higher resource constrainedness considering an early schedule.
>
> **RT3.4:** [Planning] Flexibility has a negative effect on multiproject planning by significantly increasing the variance of average total project times compared to the traditional method where multiproject plans are more predictable.

RT4: [Solution] With the help of the proposed minimal, minimax, maximin, and maximal structures, it is possible to specify multilevel project plans with supplementary tasks and flexible dependencies in a deterministic way, and solve them both with flexible and traditional methods and algorithms. Depending on the considered constraints on time, resources or cost, it is possible to find a feasible, near-optimal solution that minimizes the (multi)project duration or other objective function(s).

Results for research theses **RT1; RT2; RT3; RT3.1; RT3.2;** and **RT3.3** were published in Kosztyán, Novák, et al. (2022).

6 Summary and Conclusion

In the current dissertation, a quantitative approach supplemented with a case study was provided to evaluate the effects of flexibility on different indicators and project databases. The aims set at the beginning of this research were successfully reached.

To model heterogeneous project databases, a unified matrix-based project-planning model (UMP) is proposed. To combine existing project databases from the literature, a compound matrix-based project database (CMPD) is proposed that can also handle flexibility. In addition, a flexible structure generator (FSG) is proposed to extend existing project databases with specified structures corresponding to the given flexibility parameter. Companies dealing with agile planning considering supplementary (prioritized) activities and dependencies in a project often make decisions and estimates based solely on previous experience. The defined structures can enhance the planning of projects by considering their attributes and demands as well. Traditional algorithms can also be tested in flexible project management environments by providing new combinations of the structural- and demand-related indicator values.

The proposed UMP addresses both individual and multiple projects, single and multimodal completions, renewable and nonrenewable resources, cost and quality parameters, traditional and flexible project plans. The unified database contains both artificial (simulated) and real-life data sources. The offered parsers are prepared for single and multimode completion modes as well. The proposed CMPD provides a wider range of values to test project schedules and resource allocation algorithms by introducing flexibility. The parsers, generators and indicators are available on GitHub. Table 3 summarizes the research.

6.1 Contribution to literature

No databases are currently available to help design and schedule (structurally) flexible projects. There is a lack of project related indicators that characterize flexible project plans. This research helps fill these gaps. The contributions to the literature are summarized below.

1. A unified matrix-based project-planning model (UMP) is proposed to unify a set of heterogeneous single- and multiproject databases into a compound matrix-based project database (CMPD).

2. The proposed CMPD is complemented by the ability to model flexible dependencies and completion priorities.

3. Minimal, minimax, maximin, and maximal structures are generated to specify the minimal and maximal demands with the proposed flexible structure generator (FSG).

4. Structure-related, time-related, and resource-related indicators are modified to address the flexible nature of projects.

10 single project databases, including 22 datasets from sources including Patterson, SMCP and SMFF, PSPLIB, RG300 and RG30, Boctor, MMLIB, MMLIB+, and a real-life project database were collected, processed, and combined into a matrix-based project library, together with 5 multiproject databases, such as BY, RCMPSPLIB, MPSPLIB, MPLIB1 and MPLIB2 including 10 datasets.

Current research shows a way of extending the databases to address the flexible nature of the projects. It gives flexibility-dependent versions of the complexity and the time-related and resource-related indicators of individual projects that can also be applied to multiprojects.

It provides valuable insights into different database characteristics through adapted indicators and examines the effects of flexibility on project structure and demands including the effect on multiple modes in single projects.

6.2 Practical implications

The proposed matrix-based model addresses time, cost, renewable and non-renewable resource demands, quality parameters and considers multiple completion modes for multilevel projects. The proposed method does not only unify the heterogeneous databases but also helps users to develop, evaluate and compare both traditional and flexible project scheduling algorithms. It extends databases with a wider range of indicator values to test and provides a bridge between traditional and flexible approaches using the defined structures.

As part of the research, the developed parser tool was extended with reconstructed database formats, that had been either missing from or inadequately documented in the existing literature. The newly introduced and adapted indicators can be used to evaluate and compare various project plans of specific scenarios with the help of the defined structures. Structural, complexity, time, and resource (cost) attributes support the characterization and comparison of multi-level project plans. It is possible to compare values from previous experiences, such as successful projects, or typical values from other industries, e.g., from real-life database(s).

The proposed simulation framework provides a quantitative foundation for multi-level project planning or replanning and related decisions by considering the effects of a chosen flexible scenario on other projects in the portfolio, for example, taking into account the feasibility, project scope, resources, time, etc. It is capable to find a feasible (near) optimal solution for multi-level problems with respect to various target functions and given constraints, utilizing a metaheuristic optimization engine. The planning process can be further enhanced with the sensitivity analysis of flexible project plans. The simulation tool has an intuitive graphical user interface with various project settings and visualization possibilities, e.g., to compare individual and aggregated resource levels, durations, etc.

The combined database is open to the public and solves the problem of limited data availability. It minimizes common entry barriers (time, effort, and the need for specific knowledge) to further research. The reproduction of the composite database and results are guaranteed (Kosztyán and Novák, 2022a,b), furthermore, maintenance and verification efforts are minimized with the unified format and the provided unit tests, which helps control potential contributions from the scientific or professional community. The research is expected to accelerate the collaboration between researchers and practitioners.

Current research opens up possibilities for future studies also. New indicators could be developed, and the list of existing ones could be extended from the literature. Similarly, new databases and formats can be easily incorporated once available (including flexible ones). Artificial instances could be procedurally generated based on multiple empirical indicator values from real life and from previous project experiences. The indicators can even be used as objective functions for optimizations. The effect of using different statistical distributions for activity and dependency flexibility could be another direction of research. Analyzing project programs within a portfolio is another promising area for future research.

References

Batselier, Jordy and Vanhoucke, Mario (2015). "Construction and evaluation framework for a real-life project database". In: *International Journal of Project Management* 33.3, pp. 697–710.

Bergmann, Thomas and Karwowski, Waldemar (2018). "Agile project management and project success: A literature review". In: *International Conference on Applied Human Factors and Ergonomics*. Springer, pp. 405–414.

Bernardes, Ednilson Santos and Hanna, Mark D (2009). "A theoretical review of flexibility, agility and responsiveness in the operations management literature: Toward a conceptual definition of customer responsiveness". In: *International Journal of Operations & Production Management*.

Bianchi, Mattia, Marzi, Giacomo, Dabic, Marina, et al. (2018). "Call for Papers/Special Issue: Agile beyond software-In search of flexibility in a wide range of innovation projects and industries". In.

Boctor, Fayez Fouad (1993). "Heuristics for scheduling projects with resource restrictions and several resource-duration modes". In: *The international journal of production research* 31.11, pp. 2547–2558. DOI: 10.1080/00207549308956882.

Browning, Tyson R and Yassine, Ali A (2010a). "A random generator of resource-constrained multi-project network problems". In: *Journal of Scheduling* 13.2, pp. 143–161. DOI: 10.1007/s10951-009-0131-y.

Browning, Tyson R and Yassine, Ali A (2010b). "Resource-constrained multi-project scheduling: Priority rule performance revisited". In: *International Journal of Production Economics* 126.2, pp. 212–228.

Brucker, Peter, Drexl, Andreas, Möhring, Rolf, Neumann, Klaus, and Pesch, Erwin (1999). "Resource-constrained project scheduling: Notation, classification, models, and methods". In: *European journal of operational research* 112.1, pp. 3–41. DOI: 10.1016/S0377-2217(98)00204-5.

Čapek, R., Šůcha, P., and Hanzálek, Z. (2012). "Production scheduling with alternative process plans". In: *European Journal of Operational Research* 217.2, pp. 300–311. ISSN: 0377-2217. DOI: https://doi.org/10.1016/j.ejor.2011.09.018.

Ciric, Danijela, Lalic, Bojan, Gracanin, Danijela, Tasic, Nemanja, Delic, Milan, and Medic, Nenad (2019). "Agile vs. Traditional approach in project management: Strategies, challenges and reasons to introduce agile". In: *Procedia Manufacturing* 39, pp. 1407–1414.

Ciriello, Raffaele Fabio, Glud, Jeppe Aagaard, and Hansen-Schwartz, Kevin Helge (2022). "Becoming agile together: Customer influence on agile adoption within commissioned software teams". In: *Information & Management* 59.4, p. 103645. DOI: 10.1016/j.im.2022.103645.

Conforto, Edivandro C, Salum, Fabian, and Amaral, Daniel C (2014). "Can agile project management be adopted by industries other than software development?" In: *Project Management Journal* 45.3, pp. 21–34.

Creemers, Stefan, Reyck, Bert De, and Leus, Roel (2015). "Project planning with alternative technologies in uncertain environments". In: *European Journal of Operational Research* 242.2, pp. 465–476. ISSN: 0377-2217. DOI: 10.1016/j.ejor.2014.11.014.

Danilovic, Mike and Browning, Tyson R (2007). "Managing complex product development projects with design structure matrices and domain mapping matrices". In: *International journal of project management* 25.3, pp. 300–314.

Debels, Dieter and Vanhoucke, Mario (2007). "A decomposition-based genetic algorithm for the resource-constrained project-scheduling problem". In: *Operations Research* 55.3, pp. 457–469. DOI: 10.1287/opre.1060.0358.

Denizer, Cevdet, Kaufmann, Daniel, and Kraay, Aart (2013). "Good countries or good projects? Macro and micro correlates of World Bank project performance". In: *Journal of Development Economics* 105, pp. 288–302. ISSN: 0304-3878. DOI: 10.1016/j.jdeveco.2013.06.003.

Eisner, Howard (1962). "A generalized network approach to the planning and scheduling of a research project". In: *Operations Research* 10.1, pp. 115–125.

Fernandez, Daniel J and Fernandez, John D (2008). "Agile project management—agilism versus traditional approaches". In: *Journal of Computer Information Systems* 49.2, pp. 10–17. DOI: 10.1080/08874417.2009.11646044.

Franco-Duran, Diana M and Garza, Jesús M de la (2019). "Review of Resource-Constrained Scheduling Algorithms". In: *Journal of Construction Engineering and Management* 145.11, p. 03119006. DOI: 10.1061/(ASCE)CO.1943-7862.0001698.

Fricke, Scott E and Shenbar, AJ (2000). "Managing multiple engineering projects in a manufacturing support environment". In: *IEEE Transactions on engineering management* 47.2, pp. 258–268.

Godenhjelm, Sebastian, Lundin, Rolf A, and Sjöblom, Stefan (2015). "Projectification in the public sector–the case of the European Union". In: *International Journal of Managing Projects in Business*.

Hartmann, Sönke and Briskorn, Dirk (2010). "A survey of variants and extensions of the resource-constrained project scheduling problem". In: *European Journal of operational research* 207.1, pp. 1–14.

Hartmann, Sönke and Briskorn, Dirk (2021). "An Updated Survey of Variants and Extensions of the Resource-Constrained Project Scheduling Problem". In: *European Journal of Operational Research*.

Hauder, Viktoria A., Beham, Andreas, Raggl, Sebastian, Parragh, Sophie N., and Affenzeller, Michael (2020). "Resource-constrained multi-project scheduling with activity and time flexibility". In: *Computers & Industrial Engineering* 150, p. 106857. ISSN: 0360-8352. DOI: https://doi.org/10.1016/j.cie.2020.106857.

Hazır, Öncü and Ulusoy, Gündüz (2020). "A classification and review of approaches and methods for modeling uncertainty in projects". In: *International Journal of Production Economics* 223, p. 107522.

Hidalgo, Enric Senabre (2019). "Adapting the scrum framework for agile project management in science: case study of a distributed research initiative". In: *Heliyon* 5.3, e01447.

Hobday, Mike (2000). "The project-based organisation: an ideal form for managing complex products and systems?" In: *Research policy* 29.7-8, pp. 871–893.

Homberger, Jörg (2007). "A multi-agent system for the decentralized resource-constrained multi-project scheduling problem". In: *International Transactions in Operational Research* 14.6, pp. 565–589.

Issa, S and Tu, Y (2020). "A survey in the resource-constrained project and multi-project scheduling problems". In: *Journal of Project Management* 5.2, pp. 117–138.

Johnson, Jim (2020). "Chaos 2020: Beyond Infinity". In: *Standish Group*.

Kellenbrink, Carolin and Helber, Stefan (2015). "Scheduling resource-constrained projects with a flexible project structure". In: *European Journal of Operational Research* 246.2, pp. 379–391. ISSN: 0377-2217. DOI: `https://doi.org/10.1016/j.ejor.2015.05.003`.

Kelley Jr, James E (1961). "Critical-path planning and scheduling: Mathematical basis". In: *Operations research* 9.3, pp. 296–320.

Kolisch, Rainer, Sprecher, Arno, and Drexl, Andreas (1995). "Characterization and generation of a general class of resource-constrained project scheduling problems". In: *Management Science* 41.10, pp. 1693–1703. DOI: `10.1287/mnsc.41.10.1693`.

Kosztyán, Zsolt T (2012). "Challenges of the project planning methods in the 21st century". In: *Problems of Management in the 21st Century* 5, pp. 46–60.

Kosztyán, Zsolt T (2015). "Exact algorithm for matrix-based project planning problems". In: *Expert Systems with Applications* 42.9, pp. 4460–4473.

Kosztyán, Zsolt T (2020). "An Exact Algorithm for the Flexible Multilevel Project Scheduling Problem". In: *Expert Systems with Applications*, p. 113485.

Kosztyán, Zsolt T, Pribojszki-Németh, Anikó, and Szalkai, István (2019). "Hybrid multimode resource-constrained maintenance project scheduling problem". In: *Operations Research Perspectives* 6, p. 100129.

Kosztyán, Zsolt T and Szalkai, István (2020). "Multimode resource-constrained project scheduling in flexible projects". In: *Journal of Global Optimization* 76.1, pp. 211–241.

Kosztyán, Zsolt Tibor, Novák, Gergely, Jakab, Róbert, Hegedűs, Csaba, et al. (2022). "A matrix-based flexible multi-level project planning library and indicators". In: *DS 121: Proceedings of the 24th International DSM Conference (DSM 2022), Eindhoven, The Netherlands, October, 11-13, 2022*, pp. 48–57.

Kosztyán, Zsolt Tibor and Novák, Gergely Lajos (Nov. 2022a). *Project dataset parsers to matrix-based formats*. `https://www.codeocean.com/`. Version v1. DOI: `10.24433/CO.0837444.v1`.

Kosztyán, Zsolt Tibor and Novák, Gergely Lajos (Nov. 2022b). *Project indicators and flexibility generator for matrix-based datasets*. `https://www.codeocean.com/`. Version v1. DOI: `10.24433/CO.5304543.v1`.

Lenstra, Jan Karel and Rinnooy Kan, AHG (1978). "Complexity of scheduling under precedence constraints". In: *Operations Research* 26.1, pp. 22–35.

Lova, Antonio, Maroto, Concepción, and Tormos, Pilar (2000). "A multicriteria heuristic method to improve resource allocation in multiproject scheduling". In: *European journal of operational research* 127.2, pp. 408–424.

MacAskill, Kristen and Guthrie, Peter (2017). "Organisational complexity in infrastructure reconstruction–A case study of recovering land drainage functions in Christchurch". In: *International Journal of Project Management* 35.5, pp. 864–874.

Mathworks, MATLAB (2021). "MATLAB 2021a". In: *The MathWorks: Natick, MA, USA*.

Owen, Robert, Koskela, Lauri, Henrich, Guilherme, and Codinhoto, Ricardo (2006). "Is agile project management applicable to construction?" In: IGLC.

Özkan, Deniz and Mishra, Alok (2019). "Agile Project Management Tools: A Brief Comprative View". In: *Cybernetics and Information Technologies* 19.4, pp. 17–25. DOI: `10.2478/cait-2019-0033`.

Patterson, James H (1976). "Project scheduling: The effects of problem structure on heuristic performance". In: *Naval Research Logistics Quarterly* 23.1, pp. 95–123. DOI: `10.1002/nav.3800230110`.

Payne, John H (1995). "Management of multiple simultaneous projects: a state-of-the-art review". In: *International journal of project management* 13.3, pp. 163–168.

Pellerin, Robert and Perrier, Nathalie (2019). "A review of methods, techniques and tools for project planning and control". In: *International Journal of Production Research* 57.7, pp. 2160–2178.

Pellerin, Robert, Perrier, Nathalie, and Berthaut, François (2020). "A survey of hybrid metaheuristics for the resource-constrained project scheduling problem". In: *European Journal of Operational Research* 280.2, pp. 395–416.

Peteghem, Vincent Van and Vanhoucke, Mario (2014). "An experimental investigation of metaheuristics for the multi-mode resource-constrained project scheduling problem on new dataset instances". In: *European Journal of Operational Research* 235.1, pp. 62–72. ISSN: 0377-2217. DOI: `10.1016/j.ejor.2013.10.012`.

Pritsker, A Alan B, Waiters, Lawrence J, and Wolfe, Philip M (1969). "Multiproject scheduling with limited resources: A zero-one programming approach". In: *Management science* 16.1, pp. 93–108.

Roy, B (1962). "Cheminement et connexité dans les graphes". In: *Applications aux problémes d'ordonnancement. METRA: Série Spéciale*.1.

Sánchez, Mariam Gómez, Lalla-Ruiz, Eduardo, Gil, Alejandro Fernández, Castro, Carlos, and Voß, Stefan (2022). "Resource-Constrained Multi-Project Scheduling Problem: A Survey". In: *European Journal of Operational Research*.

Serrador, Pedro (2013). "The impact of planning on project success-a literature review". In: *The Journal of Modern Project Management* 1.2.

Servranckx, Tom and Vanhoucke, Mario (2019). "Strategies for project scheduling with alternative subgraphs under uncertainty: similar and dissimilar sets of schedules". In: *European Journal of Operational Research* 279.1, pp. 38–53. DOI: 10.1016/j.ejor.2019.05.023.

Söderlund, Jonas (2005). "Developing project competence: empirical regularities in competitive project operations". In: *International journal of innovation Management* 9.04, pp. 451–480.

Sprecher, A and Kolisch, R (1996). "PSPLIB—a project scheduling problem library". In: *European Journal of Operational Research* 96, pp. 205–216. DOI: 10.1016/S0377-2217(96)00170-1.

Stare, Aljaž (2014). "Agile Project Management in Product Development Projects". In: *Procedia - Social and Behavioral Sciences* 119, pp. 295–304. ISSN: 1877-0428. DOI: 10.1016/j.sbspro.2014.03.034.

Steward, D (1981). "The design structure matrix: A method for managing the deisgn of complex systems". In: *IEEE Transactions on Engineering Management* 28.1981, pp.

Tao, Sha and Dong, Zhijie Sasha (2018). "Multi-mode resource-constrained project scheduling problem with alternative project structures". In: *Computers & Industrial Engineering* 125, pp. 333–347. ISSN: 0360-8352. DOI: https://doi.org/10.1016/j.cie.2018.08.027.

Tavares, L Valadares (1999). *Advanced models for project management*. Vol. 16. Springer Science & Business Media. DOI: 10.1007/978-1-4419-8626-9. URL: https://doi.org/10.1007/978-1-4419-8626-9.

Traag, V. A., Waltman, L., and Eck, N. J. van (Mar. 26, 2019). "From Louvain to Leiden: guaranteeing well-connected communities". In: *Scientific Reports* 9.1, p. 5233. ISSN: 2045-2322. DOI: 10.1038/s41598-019-41695-z.

Turner, Rodney J, Huemann, Martina, Anbari, Frank T, and Bredillet, Christophe N (2010). *Perspectives on projects*. Routledge.

Van Eynde, Rob and Vanhoucke, Mario (2020). "Resource-constrained multi-project scheduling: benchmark datasets and decoupled scheduling". In: *Journal of Scheduling* 23.3, pp. 301–325.

Vanhoucke, Mario, Coelho, José, and Batselier, Jordy (2016). "An overview of project data for integrated project management and control". In: *Journal of Modern Project Management* 3.3, pp. 6–21.

Vanhoucke, Mario, Coelho, José, Debels, Dieter, Maenhout, Broos, and Tavares, Luís V (2008). "An evaluation of the adequacy of project network generators with systematically sampled networks". In: *European Journal of Operational Research* 187.2, pp. 511–524. DOI: doi.org/10.1016/j.ejor.2007.03.032.

Vázquez, E Pérez, Calvo, M Posada, and Ordóñez, P Martín (2015). "Learning process on priority rules to solve the RCMPSP". In: *Journal of Intelligent Manufacturing* 26.1, pp. 123–138. DOI: 10.1007/s10845-013-0767-5.

Wiest, Jerome D (1981). "Precedence diagramming method: Some unusual characteristics and their implications for project managers". In: *Journal of Operations management* 1.3, pp. 121–130.

Williams, Laurie (2010). "Agile Software Development Methodologies and Practices". In: *Advances in Computers*. Ed. by Marvin V. Zelkowitz. Vol. 80. Advances in Computers. Elsevier, pp. 1–44. DOI: https://doi.org/10.1016/S0065-2458(10)80001-4. URL: https://doi.org/10.1016/S0065-2458(10)80001-4.

World Bank (2012). *The little data book on financial inclusion 2012*. World Bank Publications. ISBN: 9780821395097. DOI: 10.1596/978-0-8213-9509-7. URL: https://doi.org/10.1596/978-0-8213-9509-7.

Wysocki, Robert K (2019). *Effective Project Management: Traditional, Agile, Extreme, Hybrid*.

Yasaman, Arefazar, Nazari, Ahad, Hafezi, Mohammad Reza, and Maghool, Sayyed Amir Hossain (2022). "Prioritizing agile project management strategies as a change management tool in construction projects". In: *International Journal of Construction Management* 22.4, pp. 678–689. DOI: 10.1080/15623599.2019.1644757.

7 The author's publications related to the topic

International Journal Articles

Kosztyán, Z. T., **Novák, G.**, Jakab, R., Szalkai, I., & Hegedűs, C. (2022). A matrix-based flexible project-planning library and indicators. In: *Expert Systems With Applications*. DOI: doi.org/10.1016/j.eswa.2022.119472

Kosztyán, Z. T., Jakab, R., **Novák, G.**, & Hegedűs, C. (2020). Survive IT! Survival analysis of IT project planning approaches. In: *Operations Research Perspectives*, 7, 100170. DOI: doi.org/10.1016/j.orp.2020.100170

Jakab, R., **Novák, G.** (2018). Project management approaches in application management services. In: *Chapters from the Academic Aspect of Project Management-Research and Teaching Methodologies Volume II., pp. 152-171. (ISBN: 9786150042190).*

Under review

Novák, G., Kisgyörgy-Pál, M. (2022). Multi-level project planning and simulation using a matrix-based model and nonlinear tardiness compensation profiles. Under review in: *Annals of Operations Research*.

Proceedings

Kosztyán, Z. T., **Novák, G.**, Jakab, R., & Hegedűs, C. (2022). A Matrix-based Flexible Multi-level Project Planning Library and Indicators. In: *Proceedings of the 24th International DSM Conference (DSM 2022)*, Eindhoven, The Netherlands, October, 11-13, 2022 (pp. 48-57). DOI: doi.org/10.35199/dsm2022.06

Novák, G. (2022). Evaluating the effects of flexibility on project planning databases and indicators. In: *PMUni 2022 Workshop Conference Papers*, pp. 191-206. International Conference on Project Management, Budapest, Hungary. (ISBN: 978-615-6226-04-4).

Conferences

Novák, G. (2022). Evaluating the effects of flexibility on project planning databases and indicators. Poster. OGIK-ISBIS 2022 Conference Proceedings, pp. 53., Budapest Business School, Salgótarján, Hungary.

Novák, G., & Jakab, R. (2021). Multi-level project planning and simulation using different delay cost profiles. Abstract. 15th International Conference on Economics and Business, Hungarian University of Transylvania, Miercurea Ciuc, Romania.

Novák, G., & Jakab, R. (2019). Multi-level Project Planning and Simulation using Earliness/Tardiness Compensation Profiles. Abstract. OGIK-ISBIS 2019 Conference Proceedings, pp. 44-45., Milton Friedman University, Budapest, Hungary.

Kisgyörgy-Pál M., & **Novák, G.** (2019). Többszintű projekttervezés és szimuláció mátrixalapú modell alkalmazásával a késedelmi költség hatásainak bemutatására. Abstract. Ipar napjai konferencia 2019, Conference Proceedings, pp. 53-54., University of Debrecen, Debrecen, Hungary.

Jakab, R., & **Novák, G.** (2019). Application Lifecycle Management: evolution and revolution. Abstract. OGIK-ISBIS 2019 Conference Proceedings, pp. 51-52., Milton Friedman University, Budapest, Hungary.

Novák, G., & Jakab, R. (2018). A parser for standard datasets in project scheduling and simulation. Abstract. In: Bacsárdi, L., Bencsik, G., Pödör Z. OGIK-ISBIS 2018 Conference Proceedings, University of Sopron, pp. 20-21., Sopron, Hungary ISBN: (9786158109802)

Jakab, R., **Novák, G.** & (2018). Simulation and modeling of flexible projects and Application Management. Abstract. In: Bacsárdi, L., Bencsik, G., Pödör Z. OGIK-ISBIS 2018 Conference Proceedings, University of Sopron, pp. 47-48., Sopron, Hungary ISBN: (9786158109802)

TABLE 3: Research summary

Item	Statement
RQ1:	*How to create a unified model that can represent the heterogeneous project and multiproject databases available in the literature?*
RA1:	A model can be created that unifies the different project and multiproject database formats from the literature, including time, cost, renewable-, nonrenewable-resource and quality demands. Existing databases can be imported and further extended with flexible tasks and dependencies into a single, matrix-based database.
RT1:	[Model] The proposed unified matrix-based project-planning model (UMP) can represent both traditional and flexible single project, multiproject, and program plans. It addresses the demands of renewable and non-renewable resources, time, cost, and quality with single and multiple execution modes.
RQ2:	*How the flexibility of single- and multiproject plans can be modeled?*
RA2:	Flexible project plans can be generated from existing traditional (multi)project plans and new possible structures can be added to the model to improve the planning process.
RT2:	[Structures] The flexible structure generator (FSG), is able to specify possible minimal, minimax, maximin, and maximal matrix-based structures corresponding to a defined flexibility parameter, which can be added to the model. The planning phase of projects is improved by considering these additional outcomes with their demands.
RQ3:	*What characterizes the topology (structure) and the different demands of the flexible project and multiproject plans?*
RA3:	Existing project-related indicators for topology, time- and resource-related demands can be adapted for flexible projects and multiprojects to analyze the effects of flexibility.
RT3:	[Indicators] There is a relationship between the modeled flexibility and topology, time-, and resource-related indicators.
RT3.1:	[Topology] With an increased rate of flexibility, structural indicators show reduced complexity and reduced serial completions (higher parallelity) for minimal structures.
RT3.2:	[Time] As the rate of flexibility increases, time-related indicators show decreased project duration and increased average slack ratio.
RT3.3:	[Resources] With increased flexibility ratio, resource-related indicators show higher average resource utilization and higher resource constrainedness considering an early schedule.
RT3.4:	[Planning] Flexibility has a negative effect on multiproject planning by significantly increasing the variance of average total project times compared to the traditional method where multiproject plans are more predictable.
RQ4:	*How is it possible to find feasible (sub)optimal solution for the single- and multiproject plans considering flexibility?*
RA4:	Flexible multilevel projects can be scheduled and near-optimal solutions can be found. A simulation framework can be constructed to handle flexible dependencies and supplementary tasks.
RT4:	[Solution] With the help of the proposed minimal, minimax, maximin, and maximal structures, it is possible to specify multilevel project plans with supplementary tasks and flexible dependencies in a deterministic way, and solve them both with flexible and traditional methods and algorithms. Depending on the considered constraints on time, resources or cost, it is possible to find a feasible, near-optimal solution that minimizes the (multi)project duration or other objective function(s).