Resilient Project Scheduling Using Artificial Intelligence: A Conceptual Framework

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Abstract. This paper explores the role that Artificial Intelligence (AI) can play in building resilient project schedules. Based on a literature review and brainstorming sessions, we introduce a conceptual framework that details how AI-enabled predictive and prescriptive analytics can be leveraged to improve project schedule resilience. The latter specifies the potential of AI to make use of historical and real-time data to better contain the effect of disruptions on project schedules.

Keywords: Project schedule · Artificial Intelligence · Uncertainty · Resilience.

1 Introduction

Project management with its various knowledge areas according to the Project Management Body of Knowledge (PMBoK) represents a growing subject in different disciplines in research. Attending effectiveness in managing project and especially in building schedules remains a challenge [1]. Change is part of a project process. Living with change, and having the ability to adapt project schedules quickly to disruptive unforeseen events is part of project management capabilities. This has been treated in literature under resilience for project management. Project risk management and dealing with uncertainties in project schedules has represented an important field in engineering oriented project management literature. Recent trends in literature defend the fact that facilitating change is more effective than attempting to prevent it [2]. For a project organization, building the ability to respond to unpredictable events is more important than trusting the ability to plan for disaster. In the same time, we witness the relevant diffusion of industry 4.0 driven technologies in organizations, through integrating information and communication technologies within organizations [3]. These technologies enable autonomous and dynamic processes through the joint deployment of big data and Artificial Intelligence (AI). Similarly, historical data stemming from past projects and real-time data on current projects can be extracted to fuel AI models and timely derive scheduling decisions. In particular, such models will be used to intelligently anticipate and quickly respond to different disruptions.

Existing research has tended to focus on optimizing project scheduling problems for a proactive strategy. This raises many questions about whether AI and available data should be used to build resilient project schedules through both proactive and reactive strategies. In this preliminary work, we follow an exploratory approach to understand how AI techniques can be leveraged to bring resilience to project schedules. First, we conducted a literature review in order to identify the existent knowledge related to our research question. Based on a critical analysis of the literature, we conducted three brainstorming sessions over which we develop a conceptual framework that indicates how AI can be used in this field.

The paper is decomposed into seven sections. Sections 2 and 3 give a brief overview of existing literature on uncertainty and resilience in project management, and especially project scheduling. Section 4 investigates the existing AI techniques and analytics. Section 5 presents the notable works on AI in project scheduling. In section 6, we expose the proposed conceptual framework for resilient project scheduling. Finally, Section 7 provides directions for future research at the confluence of resilience, project scheduling and AI.

2 Project Scheduling Under Uncertainty

Uncertainties in projects can be triggered by internal or external factors. The internal factors are those directly related to the project and can be organizational, related to the project's scope, or available resources. External factors are rather related to the market, technology, sociopolitical, environmental, and logistics [4].

A growing body of literature has investigated project scheduling problem under uncertainty of activity duration, resource usage and availability [4]. In the recent literature reviews presented in [4,5], one can see that project scheduling problems are classified into the following main categories: "*Basic Project Scheduling Problem (PSP), Resource-Constrained Project Scheduling Problem (RCPSP), Resource-Constrained Project Scheduling Problem with multiple objectives (Multi-Objective RCPSP), Multi-Mode Resource-Constrained Project Scheduling Problem (MRCPSP), Time/Cost Trade-off Problem (TCTP) and Resource - Constrained Multiple Project Scheduling Problem (RCMPSP)*". To overcome uncertainty, proactive and reactive strategies are widely adopted. For more details on the specific features of these problem categories, the related modeling approaches and solution procedures, readers can refer to [4,5].

3 Resilience

To understand resilience, it's important to differentiate it from other notions and concepts that are closely related to it as reliability, robustness and agility. For this purpose, some of the notable definitions of these concepts are presented in Table 1. For more definitions, the interested readers can refer to [6,7,8,9]. In this research, we consider that resilience brings the broadest sens of dealing with disruptions whether they are internal or external to the system. As such, its attainment relies on flexibility, robustness, reliability and agility. An in-depth analysis of the literature in order to identify a common definition of resilience allows us to identify three interrelated notions: system, disturbance and equilibrium [10,11,12,13].

Table 1: Definition of some resilience related notions

Notion	Definition
Agility	*"an iterative approach to delivering a project throughout its life cycle, based on the maximization of simplicity and quality and with flexibility focusing on the continual readiness to embrace change."*[2]
Robustness	*"the ability of a system or product to perform its intended function, with the presence of noise factors, in a consistent manner."*[14]
Reliability	*"a key performance indicator of any industrial production system, is the probability that a system will be able to perform its function without failing for a specific time period under certain operating conditions."*[15]
Resilience	*"the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation."*[16]

Resilience represents the capacity of the system to find an equilibrium after undergoing a disruption. The resilience can be measured through specific indicators in terms of: time needed to regain the equilibrium for the system, amount or cost of damages caused by the disturbances, and it could be the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior [10].

Despite the progress of literature, project resilience in particular remains a concept for which in-depth bibliographical references remain limited [11]. Based on an empirical study on major infrastructure projects, this concept was first introduced in [12] and defined as: *"(i) the project system's ability to restore capacity and continuously adapt to changes and (ii) to fulfill its objectives in order to continue to function at its fullest possible extent, in spite of threatening critical events."* In [13], project resilience is defined as the capacity of the project system to be aware of its surroundings and vulnerabilities, and to adapt in order to recover from disruptive events and achieve its objectives. According to [17], resilience in project can be defined through four criteria: (i) have enough free slacks, (ii) free slacks are distributed evenly in the schedule, (iii) have enough interval between the finish time of an activity and the start time(s) of its successor(s); and (iv) intervals are distributed evenly in the schedule. In this vein, Yeganeh and Zegordi [14] incorporate resiliency criteria based on activity float in building project schedule under uncertainty.

4 AI Techniques and Analytics

Different definitions of AI can be found in the literature. In [18], the authors define AI as a system's ability to accurately interpret external data, learn from the data, and use what it learns to complete specific goals and tasks.

Table 2. Summary of papers using AI in project scheduling.

Ref.	PM proc. group	Uncertain parameter(s)	Type of analytics	AI techniques
[19]	P	Duration	Prescriptive	RL
[20]	P/E/M&C	Effort Arrival of tasks Employee availability	Prescriptive	QL
[21]	P	Tasks' dates Duration	Prescriptive	GA, Parallel Schedule Generation Schemes
[22]	P/E	Uncertainty at early planning stages	Prescriptive	Mining approach Case-based reasoning
[23]	P	Duration	Predictive	ANN
[24]	P	Duration	Predictive	Nearest Neighbour
[25]	M&C	Duration	Predictive	SVM
[26]	P	Effort and duration	Predictive	ML
[27]	P/M&C	Duration	Predictive	ANN
[28]	P	Product development projects	Predictive	ANN, Fuzzy neural system
[29]	E/C	Projects delay risk	Predictive	ML

In the sequel of the availability of massive amounts of data generated by the Internet and the breakthrough advancement in computing over the last years, the popularity of AI has soared. The main techniques of AI are pattern recognition (PR), machine learning (ML), deep learning (DL), and reinforcement learning (RL), where many of them are related. Among the methods and algorithms that are used in these techniques, one can list artificial neural networks (ANN), support vector machines (SVM), Q-learning (QL), decision trees, fuzzy logic, evolutionary algorithms such as Genetic Algorithm (GA) and so on. Let us briefly introduce the above-mentioned AI techniques. For more details about these AI techniques, we refer the readers to [30,31,32] and related works.

Analytics can be defined as the use of data stemming from different sources and quantitative analysis to gain insights and drive informed decisions. As such, it is clear that advances in AI techniques will take analytics one step forward by improving its capabilities. Analytics includes three main stages characterized by different levels of difficulty, value, and intelligence [33]: (i) descriptive analytics, answering the questions "What has happened?", "Why did it happen?", but also "What is happening now?" (mainly in a streaming context); (ii) predictive analytics, answering the questions "What will happen?" and "Why will it happen?" in the future, and (ii) prescriptive analytics, answering the questions "What should I do?" and "Why should I do it?". However, as noted in [34], prescriptive analytics, which is aimed at making quicker, better, and optimized data-driven decisions, is still less mature than descriptive and predictive analytics, and as such, it is increasingly attracting the attention of researchers. AI techniques are particularly prominent in advancing predictive and prescriptive analytics.

5 AI in Project Management and Scheduling

Very recently, some surveys have been conducted in order to investigate the use of AI in project management [35,36,37,38]. The initial applications were mainly concerned with project information, project tasks, critical path method, and program evaluation and review technique where noticeably most of them are related to project scheduling [39]. For instance, in [39] the authors stated that AI could be used to analyze large datasets to find patterns, trends, and problems that need attention, based on knowledge from previous projects. AI techniques could also be leveraged to monitor how the project is going and make changes to future activities if needed. As such, AI can be particularly useful in project scheduling, costing and risk management and can be deployed in both project planning and control, which is in harmony with the findings of the recent surveys presented in [37,38]. Furthermore, AI can be used to assess the strengths of employees and leverage that to improve projects and support management and also to assist in the day-to-day tracking of projects to identify anomalies and outliers. Robotic Process Automation (RPA) is another prevalent application of AI in projects [40]. RPA can indeed be deployed to help project managers in their day-to-day work by freeing them from repetitive, high-volume tasks, like merging data from different systems to generate reports and project documents.

Table 2 reports some of the most relevant papers that use AI techniques and methods in project scheduling under uncertainty. Following the PMBoK, the second column of the table (PM proc. group) indicates for each paper the involved project management process group, namely planning (P), Executing (E), Monitoring and Controlling (M&C). The third, fourth and fifth columns provide for each paper (Ref.) the considered type of uncertainty, analytics and AI techniques, respectively. AI techniques are used either to develop project schedules and hence support decision making [19,20,21,22] or to predict more accurately the inputs of project scheduling, such as activity duration [23], or some project performances such as the project duration and cost [24,25,26,27,28] or delay risks [29]. Most of the works that include AI-enabled prescriptive analytics are using

AI techniques along with optimization techniques to develop "better" project schedules. It is worth noting here that some meta-heuristics such as GA and modeling techniques such fuzzy logic, are often considered as AI techniques. For purpose of illustration, only [21] has been cited here. Markedly, the works devoted to the construction of project scheduling under uncertainty combining ML, DL and RL with optimization techniques are rather scant, even though the latter are often aimed at incorporating uncertainty. Only a few papers try to develop a resilient project schedule [17,14] but they do not use AI techniques. Using these techniques to build a resilient project schedule is hence very promising.

6 Conceptual Framework

Given the importance of adopting systemic approach in building resilient project schedule, the proposed conceptual framework (see Fig. 1) is based on three fundamental process groups in project management: Planning - Executing and Monitoring & Controlling. In the following, we detail the conceptual framework from the general vision of how AI can be useful to project scheduling according to project process groups; to the specific aspects focused on how available data can allow this.

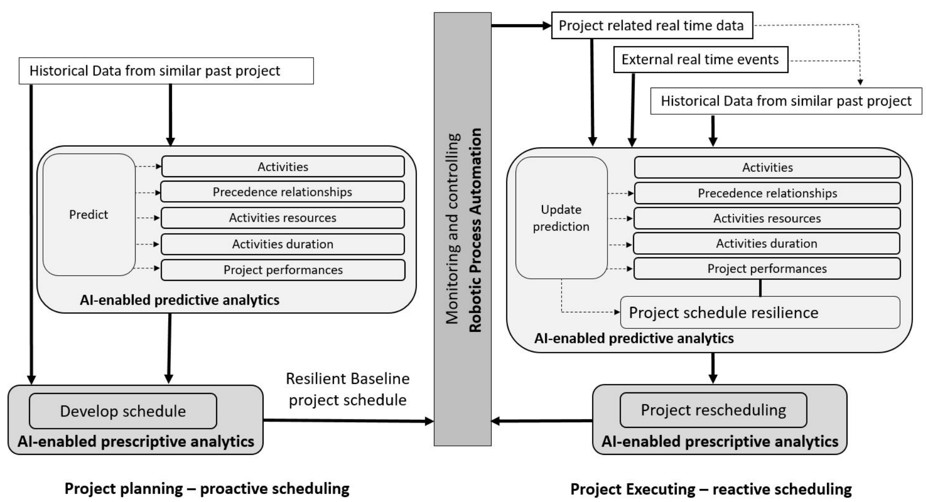

Fig. 1. Framework for building AI-enabled resilient project scheduling

First, in planning, we call for a proactive approach to build a resilient baseline schedule. During execution, the project schedule will be updated following a reactive scheduling approach whenever recommended by available data and predictions. Monitoring and controlling will ensure the continual transmission of available data related to the project progress. Relying on academic and professional referential literature, we select five fundamental elements of project scheduling: (1) activities, (2) precedence relationships, (3) resources, (4) activity durations, and (5) project performances (see Fig. 1). AI-enabled analytics can play an important role in predicting these elements at the planning and then during project execution. For example, artificial neural network, fuzzy neural system, support vector machine or genetic algorithm combined with K-nearest neighbor can be used to predict the real duration of a project or to tackle the uncertainties at different levels of planning [37].

Concerning data, we distinguish three main categories: (i) Historical data from past similar projects, this represents what comes from the knowledge system existing in the company allowing gathering data from all previous project experiences; (ii) external real time events allowing to consider in real time the events that may impact significantly the project schedule, this can be also understood as disruptions; (iii) and the project related real time data that includes all data coming from monitoring and controlling and from other sources that would impact the project schedule system.

We consider the importance of including resilience criteria since the development of the baseline project schedule. This resilience is based on historical data and emphasizes the learning from previous projects using AI techniques. During execution, resilience pertains to the ability of the scheduling system to react and adapt quickly to disruptions. From this perspective, the prediction of project schedule resilience will indicate in a timely manner if rescheduling is needed. Obviously, this depends on the ability of the current schedule to absorb disruptions, i.e. its robustness. The involved decisions in proactive and reactive scheduling will be facilitated by AI-enabled prescriptive analytics.

7 Discussion and Conclusions

Markedly, the application of AI to project scheduling relies on the availability of large historical datasets and project information. AI-enabled predictive and prescriptive analytics can be jointly used in this case to generate more accurate predictions and support decisions related to scheduling.

We built upon the gap identified in literature related to the scarcity of works studying resilience in project schedules. We define a conceptual framework to emphasize the value AI techniques can contribute to build better resilient project schedules. This represents a first step in a large exploratory approach we aim to create in the field.

This preliminary work will lay the ground for a more ambitious research that aims at the development and the adoption of intelligent project scheduling tools combining AI and optimization techniques. These tools should help project managers in building resilient schedules through better anticipation of disruptions and rapid adaptation. Our methodology will consider the importance of bridging the gap between project management community and AI and Operations Research specialists.

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