2018 International Conference on Communication, Network and Artificial Intelligence (CNAI 2018)
ISBN: 978-1-60595-065-5

A Literature Review on Robust Project Scheduling Under Uncertainty

Jun-ting LI and Ming-zhu ZHENG

School of Economics and Management, Xi'an Shiyou University, Xi'an 710000, China

Keywords: Robust project scheduling, Uncertainty, Proactive, Reactive.

Abstract. With the rapid development of the project management practice, large and super large scale projects become more and more common. such as aerospace engineering, logistics engineering and transportation engineering. Modern engineering has many uncertain characteristics, for instance, it has many participators, large scope and time, resource limit. The new management methods and project scheduling methods is needed urgently. Robust project scheduling which is one of project scheduling methods has become a key research field. This paper reviews the research achievement under uncertainty in three aspects: the concept of robust project scheduling and robustness measure, proactive project scheduling, reactive project scheduling. After all, the research directions are forecast in the future research.

Introduction

How to effectively deal with the uncertainty in project management is a hot issue that has been given close attention by the academic and engineering practice for a long time. Because of the rapid change of the external environment and the complexity of the project itself, in the practical execution of project, uncertain factors such as uncertain activity duration, resource conflicts, climate and environment will cause project activities not to be carried out follow the baseline plan, and then lead to the chain effects, for example: project delay, idle resources, increased cost and the like. The scheduling plan changes frequently, and the risk of the project has increased significantly. Therefore, project scheduling problem under uncertainty has become a key research content in the field of engineering project management, and attracts thousands of experts and scholars. The project scheduling methods include random project scheduling, robust project scheduling and fuzzy project scheduling. Among them, robust project scheduling aimed at consider uncertain factors and formulate a project scheduling plan with strong anti-interference capability is an important method to study project scheduling under uncertainty[1]. The word "robust" in project planning and scheduling means that normal project changes are not sensitive to progress and mandatory project goals, that is, there is no significant impact. So, it is very essential to pre-estimate the possible uncertainties, generate a robust baseline scheduling before the project scheduling plan, and constantly repair the disturbed schedule in the implementation process, minimize the adverse effects of the interference factors to the original plan .

In recent years, robust project scheduling has been developing rapidly, and scholars have summarized it from different perspectives. Researches on the area of robust scheduling have brought a great of fruitful results about generating robust scheduling plan and robustness measure, with the two main interference factors of project scheduling are time uncertainty and resource uncertainty. Zhang H.G. represented the imprecise temporal parameter and the uncertainty of the resource involved in project by fuzzy sets, also defined the robustness measure by consideration of quality robustness and solution robustness. Based on these, developed a genetic algorithm to solve the project scheduling robustness under resource uncertainty[2]. Meanwhile, researchers have been working on the construction of various kinds of algorithms to optimize the robust scheduling model, referring to the research field of computer related robustness, proposed a two-stage robust scheduling algorithm, artificial immune algorithm, genetic fuzzy algorithm, cloud genetic algorithm, particle swarm optimization algorithm and fusion, improved ant colony algorithm[3-5]. Along with the life-cycle of a development project, this paper systematically reviews the theoretical methods under uncertainty,

analyzes its advantages and disadvantages, and provides a reference for the development of the robust scheduling method.

The Concept of Robust Project Scheduling and Robustness Measure

Robustness is the performance to maintain normal work when there are uncertain factors in the system. That is, system has the ability to bear the influence of uncertainty under certain parameter perturbations. Robustness is widely used in many fields, such as robust job shop scheduling, robust scheduling of parallel machines, robot intelligence and so on. Robust scheduling is also often applied to many engineering fields, such as harvesting scheduling, flight robust scheduling, water resource applications, chemical engineering, and so on. Herroelen firstly introduced robust concept into project scheduling and established a strong robust resource allocation plan[6].

Robust project scheduling which aimed to ensure the effectiveness of the plan through robust optimization and robust control is also divided into proactive project scheduling and reactive project scheduling. Proactive project scheduling occurs at the stage of plan formulation. At the beginning of making the scheduling plan, predict various uncertain factors that may appear during project execution in advance, and directly establish a robust scheduling with strong anti-interference capability. Reactive project scheduling occurs in the stage of plan execution. In the process of project execution, repair or reformulate the scheduling plan according to the uncertain disturbance. These two stages are closely connected. In the academic field, it is generally considered that proactive project scheduling is more important, because it is not only easy to model based on the baseline scheduling plan, but also a comparison standard for later reactive scheduling[7]. However, because of the strong one-time nature of the project, no matter how high the robustness of the proactive scheduling is, it is impossible to avoid the uncertainty that may arise in the future. It is equally imperative to make remedial measures in response[5]. With the development and application of robust project scheduling, the measurement method of robustness can be generally classified as solution robustness and quality robustness[6].

Solution robustness. It is the degree of deviation between the baseline scheduling plan and the actual scheduling of the project. A more commonly used measure is $slac^k$[8] and the extent to which the activities actually begin to deviate from the beginning of the plan[6]. The former does not need to be calculated by numerical simulation, but the latter is relatively difficult to measure, and it needs to be obtained by simulation.

Quality robustness. The quality robustness is the sensitivity of the makespan to the change of the active task. In view of the uncertainty factors, a more robust plan is established for the possible interference of the benchmark scheduling plan, so that the objective function value will not be greatly disturbed due to interference in the model calculation. Generally, the objective function is for minimizing the project duration, minimizing delaying costs, maximizing the net present value and so on. Bai S.J. regarded the uncertain duration of activity as a fuzzy number, described the project schedule plan problem with the fuzzy design structure matrix, taking into account not only the uncertain activity duration but also the uncertain information transfer relationship between the upstream and downstream activities, developed the model of calculating project duration through fuzzy operation in fuzzy network environment, introduced the probability of project completion as required duration(MCR) and the marginal duration contribution rate (MCR) are introduced to solve critical path in fuzzy network and project resource-duration optimization[9].

The comprehensive evaluation index system. Generally speaking, researches always use the simulation method analyze these two relative importance of the bi-objective function. It not only ensures that the scheduling scheme meets the requirements of the performance index, but also keeps the onset time of the activity as stable as possible. Based on the classical serial schedule generation scheme, Pang N.S. puts forward a factor measuring the stability of activity and robust SSGS; with the proposition of a robust measure index, builds a double-objective optimization model of the shortest

duration (solution robustness) and robustness maximization (quality robustness) is developed; designs an improved SA algorithm to solve problems[3].

Proactive Project Scheduling

Proactive project scheduling is to protect the project from interference in the execution process, and create a robust benchmark scheduling plan with strong anti-interference ability. In the field of management, plan which is full of abundant contents, consisted of tasks, goals, and action to complete a mission. And as an major function of project management, it is one after another and runs through the whole process of the project. Consequently, in the early stage of the plan, we should have a certain arrangements for the scale of the project, project implementation general plan, the timing of the project preparation and construction, resource, the total investment and sources of funds. From the angle of time uncertainty and resource uncertainty, this paper divides the proactive project scheduling into the following four methods:

Time buffer method. It includes critical chain method and scattered buffer method. Critical chain method is a centralized buffer method, which defines three types of buffers, that is project buffer, feeding buffer and resource buffer. The purpose is to replace the traditional critical path with the critical chain, insert the project buffer at the end of the project, and insert feeding buffer in the intersection between the critical chain and the non-critical chain, so as to ensure the completion of the project on time. This method is considered as a proactive quality robust scheduling method, what counts is identification of critical chain and buffer size. And critical chain is the longest task line in a project under resource constraints. The determination of the critical chain is a process of tracing and optimizing. As to the calculation of buffer size and buffer management, Hu X.J. used Bayesian networks to identify the key risk factors, evaluate the probability of occurrence and the impact on the duration of activities. She put forward a reasonable calculation method of buffer size, and designed a dynamic buffer monitoring model based on Bayesian network risk tracing, risk transfer and project resource flow network update under dynamic execution environment[10].

Because the real project execution process is too complex, after determining the critical chain and non-critical chain, further insertion of time buffer often appears to new bottleneck processes and bottleneck resources, leading to changes in critical chain offset or fracture, parameter discontinuity and absence of activity dependence, which makes time buffer fail to play a protective role. In view of this problem, the current research is not much. Researchers are also trying to put forward some critical chain rearrangement strategies, but the problem of critical chain overflow or breakages still exists after rearrangement. Cui N.F. researched from the perspective of buffer setting mode, and put forward a scattered buffer based on STC(Starting Time Criticality) instead of critical chain centralized buffer to generate a project scheduling methods. He compared the scattered buffer plan with the rearranged critical chain scheduling plan by a simulation experiment, and come to the conclusion that when time variations of the project activity is relatively small, using scattered buffer method can also achieve better project performance[11].

Resource buffer method. In the field of project scheduling, resources often refer to human resources. However, due to the high cost of additional resources in the execution of the project, it is usually used in conjunction with the time buffer method. At the time of generating scheduling plan, taking numerical value less than the maximum resource acquisition as resource restriction, and transformed the resource uncertainty into time uncertainty. Zhang W.F. analyzed several respective CCR buffer types and their advantages and disadvantages, As well as the method of determining the time buffer. The last a CCR time buffer model based on system availability theory is proposed. Finally, the simulation software is used to test the operation of the case, and the computational reliability of the model is obtained, so as to prove the rationality of the CCR time buffer model[12].

Cumulative instability weight. Cumulative instability weight(CIW) arranges every activity in the project according to its cumulative weight and arranges the priority for the highest weight activities. It

effectively controls the impact of uncertain disturbances on the whole scheduling plan, and makes the stability of the scheduling plan the best.

The analysis method of worst case. In some uncertain conditions, the probability distribution characteristics of the project parameters are difficult to obtain, and the project scheduling model based on the probability distribution will no longer be applied. The robust optimization target of the worst scene in the field of machine scheduling, that is, minimize the maximum regret value, become an effective method of project scheduling. Researches solved the scheduling problem and modeling by minimizing the maximum absolute regret value in all scenarios and mean square variance[13].

At present, the research of proactive project scheduling is becoming more and more active. The uncertainty interference in the actual project execution is mainly focused on time interference and resource interference. The above mentioned time buffer method and resource buffer method are the mainstream approaches. Besides, some heuristic algorithms and intelligent algorithms arose in recent years, but these two are based on some heuristic rules (with more priority rules) and search method for rapid solving problems, can not guarantee the quality of solution. However, there are few literature on how to develop a robust proactive project scheduling plan under resource uncertainty, and the researches just started.

Reactive Project Scheduling

Reactive project scheduling refers to timely repair or rescheduling for temporary and unforeseen uncertainties in the process of project execution, so as to eliminate or reduce its impact on scheduling plan. Reactive scheduling method can be divided into the following categories: completely rescheduling, emergency scheduling, repair scheduling, rush strategy, sensitivity analysis.

Completely rescheduling. Completely rescheduling is to achieve higher scheduling quality, according to the performance evaluation goals in some deterministic scheduling (such as the shortest duration and minimum cost), we should regard the unfinished activities as a complete project and schedule them again. Completely re scheduling method consisted of four types: the first is the minimum perturbation strategy which needs to realize ex-post stability when the level of uncertainty reaches a certain degree and the nature of the project changes; the second is fix resource allocation and partially adjust to the baseline scheduling, when personnel, raw materials, and other resource arrangements do not want to be disrupted; the third is priority rule scheduling, according to the sequence of activities in a priority relation list generated based on certain rules, and combining scheduling generation scheme; the last is minimize advance/delay penalty costs. In terms of the stability of the scheduling scheme, the classic resource constrained project scheduling problem (RCPSPWET) has a penalty cost with advance /delay.

Emergency scheduling. For a time sensitive reactive scheduling problem, emergency scheduling is a fragment of multiple benchmark scheduling or benchmark scheduling before or during the execution of a project. When the uncertain disturbance occurs, it can easily replace another set of scheduling schemes or fragments. Billaut and Roubellat proposed to generate a "group sequence" for each resource, that is, all or part of the sequence set of the operation group. By artificial selection of these "group sequence", multiple scheduling schemes are generated for decision makers to choose[14]. Hence, when decision makers face uncertain disturbances in real-time project execution, they can switch from one set of scheduling schemes to another, and will have a limited impact on project performance.

Repair scheduling. In some extreme cases, for the project scheduling problem with fast response, in order to recover the scheduling plan quickly, a simple scheduling technology is usually used, that is, the repair scheduling method. The simplest repair strategy is the right shift rule, which moves the activities affected by resource interruptions or priority relationships along the time axis. However, the strategy doesn't rearrange the sequence of activities, which may lead to poor scheduling quality.

Rush strategy. The most common remedy is to take some corrective actions to catch up some or all of activity Duration. Rush strategy is often used in the problems of time/cost, time/resource

equilibrium problems, multi-model issues. Ni G.Q. designed the online pre-rushing strategy, competitive ratio of the strategy, analyzed the relationship between the general strategy and the optimal offline strategies, and discovered three properties to help the project manager choosing the optimal strategy according to his own risk tolerance and forecast[15].

Sensitivity analysis. The research on sensitivity analysis is common in the field of machine scheduling, responding to a question about "if...how it will be". The domestic research on sensitivity analysis is more common in project duration simulation analysis. Based on polynomial structure-selection and optimal polynomial response surface, Liu G.Z. proposed a novel global sensitivity analysis method for conveniently evaluating the sensitivity of complex system parameters and derivative-integral sensitivity analysis method which can quickly and effectively get the sensitivity results of structural variables[16].

For reactive project scheduling, Tian W.D. divided it into two categories: under uncertainty of activity duration and under uncertainty of resources[17]. At present, the research on robust scheduling is mainly focused on proactive project scheduling, and there is less research on reactive project scheduling, especially under uncertainty of activity duration. In the field of machine scheduling, the research on reactive scheduling is relatively mature. It can be considered and applied to the project scheduling in future research.

Acknowledgement

This research was financially supported by Shaanxi Province Soft Science Research Plan Projects, 2016.05-2017.04: Research on Driver of Scientific and Technological Innovation to the Upgrading of Construction Industry (2016KRM145).

Conclusion

Robust project scheduling is a hot and difficult problem at home and abroad in recent years. Proactive and reactive project scheduling as an important branch, plenty of research achievements have appeared, but a complete knowledge system has not been formed. In this paper, we sort out robust project scheduling method through different ways of dealing with uncertain interference, so that readers can have a preliminary understanding of this field, hoping to provide some references for future research and work. In addition, the future research direction of robust project scheduling methods should be paid attention to in the following aspects:

(1) In the field of proactive project scheduling, there are many researches on solution robustness, but less research on quality robustness. Besides, the research on the comprehensive evaluation index system is of great significance to project management, and need to be explored in depth.

(2) Compared with proactive scheduling, the research achievements about reactive scheduling are relatively few. The method of reactive scheduling in the field of machine scheduling could be considered to apply to project scheduling field.

(3) At present, the research on robust project scheduling mainly focuses on uncertainty of activity duration and resource. Obviously time uncertainty and resource uncertainty may occur simultaneously, and other uncertainties may occur. Therefore, using the design structure matrix to describe these new uncertainties, and how to deal with the combination of uncertain disturbances in complex environment and the robust project scheduling considering other types of uncertainties is also a direction worthy to make further researches[18].

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