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A multi-agent model to manage risks in construction project (SMACC)

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ABSTRACT

Construction projects are subject to numerous risks that could have consequences on project achievement. They involve numerous stakeholders whose interests and demands need to be considered in the managerial decision-making process, to ensure the success of the project. Each stakeholder has his own risks and perspective on project risks. Furthermore, risk management is a dynamic process throughout the project life cycle. On one hand, risks change along the different phases of the project, on the other hand, multiple interactions have been identified between risks. For these reasons, it could be difficult to model project risks in order to manage them. In this paper, a multi-agent model (SMACC) is proposed to study this complex system. By using multi-agent simulations coupled with a stochastic approach, risk impacts can be evaluated for each stakeholder and for the whole project. These simulations make possible to test different risk mitigation strategies in order to measure their interest and then to support risk management decisions.

1. Introduction

Construction projects are complex systems. Complexity of projects is more often linked to the growing number of stakeholders. This high number of stakeholders and therefore of interfaces is a significant factor in risk. Furthermore, organizational factors and human decision processes have a main impact on risks [1]. In recent years, intensive research and development have been done in the area of construction projects risk management. It is widely recognized as one of the most critical domains and capability areas in the field of project management [2]. However, construction project objectives are not always met; many projects have been plagued by cost overruns, delays, and poor performance. An important margin exists to improve project risk management but this improvement is constrained by current practice and the lack of global knowledge. Strong gaps are identified in terms of organization and general management throughout the project, particularly with regard to the interfaces between the stakeholders, whose objectives may be different, even sometimes contradictory. The pressure on project delay and cost, the need for improved performance in the construction industry and increasing contractual obligations, lead to the necessity of a more effective risk management approach [3]. Improving the risk management process is therefore a key challenge in construction projects [4].

Project risk can be defined as effect of uncertainties on project objectives [5]: cost, time and project performance (deviations from expectations for the initial project). The performance criterion may cover various types of requirements, like technical requirements, esthetic considerations, and satisfaction of the client …. Project risk management aims to identify and assess risks in order to manage them effectively [6]. It is a dynamic process along the project life whose usual stages are risk identification, risk analysis (qualitative or quantitative), response planning and risk mitigation [7]. The importance of using a rigorous approach along all these stages has been pointed by many authors and synthetic guidelines which usually provide a general perspective on stakes, tools and methods used in research and practice of PRM [8]. In risk management process, risk analysis has a central place. Thus, to have an efficient risk management, it is necessary to have an efficient risk analysis.

The focus will be given in this article on the risk analysis stage for which a multi-agent model called SMACC (Stochastic Multi-Agent simulation for Construction projeCt) is proposed. This model must be seen as a contribution to the global PRM process: its data (model agents and parameters) require a previous identification stage, and its outputs will be used in the decision stage by risk managers. Multi-agent modeling has brought a new way to study complex systems. Because of their very simple description and response at elementary level multi-agent models are particularly well-fitted to the description of complex interactions which naturally result from the relations between agents and from the dynamic character of the system [9]. SMACC can be used to simulate the progress of a project while integrating possible risks causes and to evaluate their impact on the project. By running the simulation a large number of times, a statistical view on project results under risk can then be built. It is also possible to simulate the impact of different possible strategies in order to analyze their performance. After highlighting the interest of multi-agent systems for construction project, we will

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expose the SMACC model according to the ODD protocol [10]. Finally, we will present the application of the SMACC model to a real project to illustrate its performance.

2. Interest of multi-agent systems for construction projects

2.1. Issues in construction projects

Construction projects lead to complex decision situations. The decisions can be related to the whole project (definition of the budget), a specific task (what kind of concrete is the most relevant for this work?), a stakeholder (is it necessary to hire a temporary worker to replace a sick worker?) etc. The consequences of decision can have a major impact on the project success or failure (in terms of cost, time, and quality), and on its environment (injured people or fatalities, environmental damage, political consequences, etc.).

Moreover, the decisions have to take into account different types of stakeholders: client, contractors, workers, user, etc. These stakeholders may have different objectives (project cost, quality/performance, etc.), different views on the project and different roles and responsibilities in the project (decision-maker, user, etc.). It was shown that the public decision-making problem, when different stakeholders have contradictory objectives, has no optimal solution that can be agreed by all stakeholders [11]. Accounting for the variety of points of view is thus a key issue of construction project decision-making.

Another issue is related to the uncertainty. Construction projects generate an important technical and organizational complexity associated with many uncertainties. A large range of uncertain events can affect/influence the project and, thus, its success. Some of them are the increase of material prices, an accident during the construction, a decision-maker change of mind (and thus of the project expectation), etc. The fact that risk events are diverse in their nature and origin (a specific task, a specific resource, a specific stakeholder, the environment …) makes their analysis impracticable. To answer this issue, a large variety of tools and methods allowing to identify, to formalize, and to assess risks in construction project such as the risk list, risk matrix, risk map and Risk Breakdown Structure (RBS), have been proposed [12–15].

One additional and major drawback of available risk analysis is the poor attention paid to interactions. Interactions have to be considered between stakeholders, as the behavior of one stakeholder may influence the behavior of another. More generally any risk event may induce additional risk events, leading to a complex system whose explicit description is impossible [16]. The main difficulty is to identify and evaluate these interactions [17]. Risk network could be a solution to formalize interactions [18] but this method is project specific and is difficult to generalize. For each project, a complete network must be built, requiring a large investment. Furthermore, this network does not take into account the reacting capacity of stakeholders and their relations (dynamic perspective) [19]. Indeed, it requires considering the dynamic aspect of the project as most of the interactions are due to the chaining of the cause/consequence processes. For example, a fatality occurring during construction could have a direct impact on the project (human impact, delay and additional cost), but also modify the characteristics of other risk events (e.g., bankruptcy of the contractor; lack of motivation of the contractor …). Moreover, it is important to take into account the dynamic responses from the different stakeholders to risks. After an accident, the company could pay a specific attention on safety on the working site. This reaction would decrease the probability of another accident but could also slower the workers' productivity. This situation could have an impact on the other stakeholders (more care about safety, new schedule, etc.). Stakeholder capacity of reaction has thus a major impact on the success of the project. It is necessary to take into account these interactions and this capacity of reaction. However, since it is impossible to consider all risk events and since a large variety of reactions can be considered when a stakeholder is faced with an occurring risk event, it is impossible in practice to formally describe the system with all its possible interactions.

To conclude, managing a project with taking into account risks requires powerful tools able to consider its dynamic aspect, the interactions between the elements of the systems, the contradictory objectives of stakeholders and the uncertainty. Describing and considering consequences of risk interactions is a common weakness of most models for management of project risk. The main reason is the complexity of interactions, which may be of various natures: (a) correlation between causes or risk sources, (b) interdependency between actions or decisions, and (c) multiple consequences that may themselves become new risk sources. In most cases risk are considered as independent and the interactions have to be described explicitly [20]. Innovative approaches have been proposed by considering logical parallel/series combinations of risk [21] or by using clustering methods, in order to explicit the risk structure matrix [22]. The fact that the explicit description of interactions remains tedious and cannot be carried out in practice. Multi-agent models have two main advantages: (a) the basic description is very simple, once the choice has been done of elementary components, which all have a simple and explicit behavior, and (b) the complexity arises from the dynamic response. This exactly corresponds to what happens for interactions.

2.2. Multi-agent systems for construction project management

Multi-Agent System (MAS) is a system composed of several autonomous entities, namely, agents. Each agent interacts with other agents and can work continuously in a complex environment. An agent acts proactively to fulfill its own goals. It works on very simple rules, according to the information it receives. The goals of the different agents may be conflicted and there is no global control.

Multi-agent systems can easily find a new application field in the construction industry since it is a fragmented, dynamic and very complex industry. Construction projects involve many parties with different levels of knowledge and conflicted goals and interests. The information is decentralized, and knowledge and experience are unevenly distributed among stakeholders. Therefore, the flexibility of MAS seems to be suitable for modeling the construction project. Accordingly, some researchers have already tried to develop MASs to solve problems in the area of construction industry, even if they usually limited the application to a small part of the global process. Some of developed agent-based systems include:

- project design: ADLIB — Multi-agent system for design collaboration [23,24],
- procurement and specification of construction products: APRON — Agent-based specification and procurement of construction product [25], EPA — electronic purchasing agent [26] and MASSS — a multi-agent system for suppliers sourcing [27],
- supply chain coordination: ABS3C — agent-based framework for supply chain coordination in construction [28] and schedule coordination: DSAS — distributed subcontractor agent system [29,30].

These different MASs are interesting, while remaining limited to a specific domain of the construction project and not considering uncertainties. Few MASs developed for construction project take into consideration risk or uncertainties. For example, MASCOT — a multi-agent system for construction claims negotiation [31,32] used Zeuthen's strategy [33] based on Bayesian learning approach to simulate negotiation on project design between contractor and designer or contractor and client for risk allocation. Nevertheless, these two models still consider only a limited part of the global project process.

Rojas and Mukherjee [34–36] proposed a MAS to simulate the whole construction phase of a project. The model aims at assisting students and young engineers in understanding the construction process and decision-making process by simulating the construction project.