Risk Management in Construction Project Using Agent-Based Simulation

Franck Taillandier[1] and Patrick Taillandier[2]

[1] UMR 5395 I2M -Univ. Bordeaux- 351 cours de la Libération, 33400, Talence
[2] UMR IDEES - Université de Rouen - 7 rue Thomas Becket, 76821 Mont Saint-Aignan
franck.taillandier@u-bordeaux1.fr, patrick.taillandier@gmail.com

Abstract. In recent years, intensive research and development have been done in the area of construction project risk management. Indeed, an efficient risk management is mandatory to project success. However, implementing such a management is complex because of the diversity and the dynamic nature of the risk. Moreover, each of the project stakeholders has his/her own risks, his/her own vision and his/her own action on the project and on risks. In this paper, we propose an agent-based model called SMACC to assess the impact of risks on the project. This model allows to test different risk mitigation strategies to measure their impact on the project. An application on a real project is also proposed to demonstrate the operability and the value of the proposed approach.

Keywords: Construction project, Risk management, Agent-based modeling.

1 Introduction

Construction projects are subject to many risks (organizational, human or economic). These risks can have a deep impact on the success of the project. Being able to manage them is one the major aims of project management. To answer this aim, many methods and tools have been developed to identify and evaluate the risks [1]. However, the complexity inherent to construction projects makes very difficult their global management. 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 have been identified in terms of organization and general management throughout the project, particularly with regard to the interfaces between the actors, 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 [2].

In this article, to address risk analysis issues in construction projects, an agent-based model called SMACC (Stochastic Multi-Agent simulation for Construction projeCt) is proposed. 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

J.M. Corchado et al. (Eds.): PAAMS 2014 Workshops, CCIS 430, pp. 34–43, 2014.

risk can then be built. It is also possible to simulate the impact of different possible strategies in order to analyze their performance. After presenting some related works (Section 2), we will introduce the SMACC model (Section 3). Finally, we will present the application of the SMACC model to a real project to illustrate its performance (Section 4).

2 Related Works

Some researchers have already tried to develop MASs to solve problems in the area of construction industry. Their application is often limited to a small part of the global process:

- Project design (ADLIB - Multi-agent system for design collaboration [3]) ,
- Procurement and specification of construction products (APRON - Agent-based Specification and Procurement of Construction Product [4], EPA: Electronic Purchasing Agent [5] and MASSS: a multi-agent system for suppliers sourcing [6]),
- Supply chain coordination (ABS3C: Agent-based framework for supply chain coordination in construction [7]) and schedule coordination (DSAS: Distributed Subcontractor Agent System [8]).

These different MASs are interesting, but consider only a specific domain of the construction project and they do not consider uncertainties. Few MASs developed for construction project take into consideration risk or uncertainties. It is the case of MASCOT -A multi-agent system for Construction Claims Negotiation [9] is based on Bayesian learning approach to simulate negotiation between contractor and designer (on project design) or contractor and client (for risk allocation). Nevertheless, this model still considers only a limited part of the global project process.

Rojas and Mukherjee [10] 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. Users can interact with the system by changing project parameters such as the resources requirements. The simulation is based on user interactions, and stochastic events that may arise during the course of the project. The developed MAS do not automatically generate decisions; this task being left to the user. Our challenge with SMACC will be, as in Rojas and Mukherjee model, to consider a stochastic environment, but also to integrate a decision model for stakeholders within the simulation.

3 Model Description

The purpose of SMACC is to simulate a construction project throughout its life cycle, from the feasibility phase to the end of the implementation phase, considering potential risks. It proposes a neutral perspective on risks, considering the whole project and all stakeholders. As results, SMACC estimates the project cost and duration, and the quality of the project activities/tasks. The simulation results can aid in the decision making process by testing different risk mitigation strategies and by measuring their impact on the project. SMACC is based on a chronological perspective of the project, highlighting the role of the stakeholders during the progress of the project.

The model is composed of many entities that have to be taken into account to simulate in a realistic way the dynamic reference system. In SMACC, we chose to represent all the entities composing the reference systems as agents, even when they are non-living entities (contract, operator instructions, etc). This choice helps to simplify the interaction process between the entities.

SMACC considers four agent families and nine types of agent:

(1) Project: Project agent (one global agent),

(2) Initial project descriptors: Stakeholder (project manager, contractor, etc.), Task (excavation work, painting, etc.), Resources (monetary resources, human resources, etc.), Contract (engagement of a company to perform a task with defined time, quality, etc.),

(3) Instructions: Instruction Agent (instruction of a manager to an operator to perform a task with expected delay, quality, etc.),

(4) Risks: Risk factor (high rate of work, low security level, etc.), Risk event (working accident, error on design, etc.) and Risk consequence (task delay, additional cost, etc.).

The Project agent is a global agent which is characterized by a set of tasks, the project objectives and constraints (time, expected performances and resource allowed), the price of each unit of resources (reusable or consumable) and the current situation (time spent, resources used…).

The second family of agents groups the various agents describing the project contents. Stakeholders correspond to the various people working on the project (they can be described as organisms, services or individuals). Stakeholder can have two roles: manager and operator. The operator role is the task execution. Each task has one person in charge (manager) who is responsible for its good realization. The responsibility of each task is directly assigned by the contract. Into this agent family, Contract agent has a center place. It includes all documents making a link between stakeholders and the project requirements according to each task. Contract specifies for a task the resources allowed, the expectations (delay, quality), the manager and the operator. To work on a task, operators have to call up resources (reusable and consumable). Tasks are characterized by a quantity of minimal and maximal resources of each type (reusable and consumable). Minimal resources correspond to the minimal quantity of resource necessary to make the task progress. Maximal resources correspond to the maximal quantity of useful resources to work on a task.

The third family contains Instruction agents. These agents correspond to the communication between a manager and an operator. The manager gives instructions to the operator of a task to favor cost, productivity, or quality. The operator must understand and translate these instructions into concrete actions.

Risk agents (risk factor, risk event and risk consequence) are defined in order to model risks, from their cause to their consequences. A risk factor is a project situation that could have an impact on project risks (for example "A low quality of the landscaping" that could increase the risk event "Problem of foundations realization"). A risk factor is described by a threshold on a variable which describes a stakeholder, a resource, a task or a contract. Risk events are events which can affect a parameter of the project, and thus, the project objectives. They are linked to a task or to a stakeholder and are defined by a probability of occurrence and by an impact on a variable. For example, the risk event "Error on the plan" could have a probability of 0.1 and an impact on the construction task progress. Risk consequences are the sum of consequences due to the risk events which occurred for a defined task or stakeholder.

SMACC is based on project planning. Tasks can be performed successively or simultaneously. The planning considers the precedence relationships between tasks. For each task, a contract defines an operator (contractor, designers…) and a manager. The progress rate, the cost and the quality of the work done by the operators depend on the characteristics of operators and on those of the manager. Risk events (natural hazard, worker accident…) could have an impact on cost, delay and quality. Risk events occur randomly following predefined laws.

Each step of the simulation corresponds to a working day. At each working day, the following processes are carried out, as described on Figure 1:

Process 1 - Update task status: each task updates its status. A task is considered as completed if the work progress on this task reaches 1. A task becomes executable is all the previous task are completed.

Process 2 - Check end condition: the project checks the status of all tasks. If all the tasks composing the project have the status "finished", the project is considered as completed and the simulation ends. There are two other conditions which can end the simulation: if the simulated project duration exceeds twice the planned/target duration or if the simulated project cost exceed twice the budget, the project is considered as failed and the simulation ends.

Process 3 - Assess priorities: each task assesses its priority. Tasks belonging to the critical path have the highest priority. Other tasks allow a delay of one or several days without impacting the total duration of the project and have a priority that depends on this margin; the higher the margin, the lower the priority. PERT diagram [11] is used to calculate the margin.

Process 4 – Give instructions: each manager of an executable task establishes a strategy by giving prior direction– i.e. creates an *instruction* agent - to operators. This instruction is built by choosing a Productivity/Quality/Cost vector value. The instructions depend on (a) the current status of the project and (b) the specific interest this stakeholder has regarding these three dimensions. Risk events can modify the instruction (increase or decrease normal values). For example, a bad perception of a delay situation can lower the importance given to the Productivity value.

Process 5 - Understand instructions: when an operator receives instructions, he/she can follow them or not. His/her behavior may depend on a variety of factors, like misunderstanding the manager instructions, or an exterior pressure on the operator to quickly finish his/her task. An operator has to build his/her own PQC vector by considering all orders he/she has received, his/her preferences and potential risk consequences.

Process 6 - Assign resources: for each task, each manager chooses the monetary resources to share between the operators that must take the task in charge. The quantity of monetary resources by day given by the manager to an operator depends on the will of the manager to limit the cost, the duration, on corrective penalty in case of work of low quality or delay and on risk consequences. The money given by the manager for each task can be freely used by the operators. The operator can divide the money as he/she wants to his/her tasks. This repartition is described in process 7. The assigned money is added to the monetary resources of the stakeholder and is withdrawn from the project monetary resource.

Process 7 - Allocate resources (Operator): each operator that has to work on one or several tasks distributes his/her resources on the tasks. For this, she/he assesses the ideal resources (quantity and quality) for the task which correspond to the minimum quantity and quality necessary to reach the task objectives (without considering risks). Then, the operator analyzes his/her available resources and can buy consumable resources or rent reusable resources using his/her own monetary resources. Risk events can also modify the purchasing or rental costs (e.g. "new tax on the temporary workers", "Increase of iron market price"). Finally, the operators distribute their resources between their tasks. The distribution of owned reusable resources is based on the difference between ideal resources and rented resources, weighted by the productivity indicator. More a task requires a high productivity and higher the quantity of resources to reach the ideal resources is, more the operator allocates resources.

Process 8 - Make progress tasks (Task): each task computes its progresses according to the resources used (quantity and quality), its characteristic and the consequences of the occurred risk events (accident, material failure…). The task quality depends on the quality of the resource, the quality instruction (higher the quality instruction higher the quality) and the possible occurrence of risk event impacting quality (e.g. "design options not adapted to working constraints").

Process 9 – Pay the managers: when a task is completed, the manager of the task is paid. The quantity of money paid to the manager depends on the contract (due monetary amount), the task achievement in terms of time/duration (comparison between the time spent and the time allowed) and quality (comparison between required quality and task quality), resources used (comparison between assigned and expected resources) and risk events (e.g. "financing fault"). The quantity of money paid, i.e. quantity of monetary resources, is removed from the project resources and added to the manager resources.

Process 10 – Update stakeholder's characteristics: the evolution of the project or external events can modify the motivation and the expertise of stakeholders. For example, the retirement of a skillful employee can reduce the technical expertise of a stakeholder. A bad communication between the manager and the operator can reduce his motivation. This action is executed once by step and stakeholder characteristics are updated.

Process 100 – Update risk factors: the risk level depends on the entities concerned by the risk factor (stakeholders, task, contract, instruction or other risks) and on the risk factor characteristics (threshold and importance). The more the value exceeds the threshold and the higher is the importance of the risk factor, the more the probability of the risk event will be impacted.

Process 101 – Update risk events: each risk event updates its probability of occurrence according to the risk factors that can induce this risk event.

Process 102 – Simulate risks: The risk event simulation consists in a random draw. If the random number is inferior to the risk event probability, the risk event occurs and then induces consequences; otherwise nothing happens at this time step. SMACC simulates each risk event and sums the consequences that concern the same stakeholder or the same task to evaluate their impact on the project.

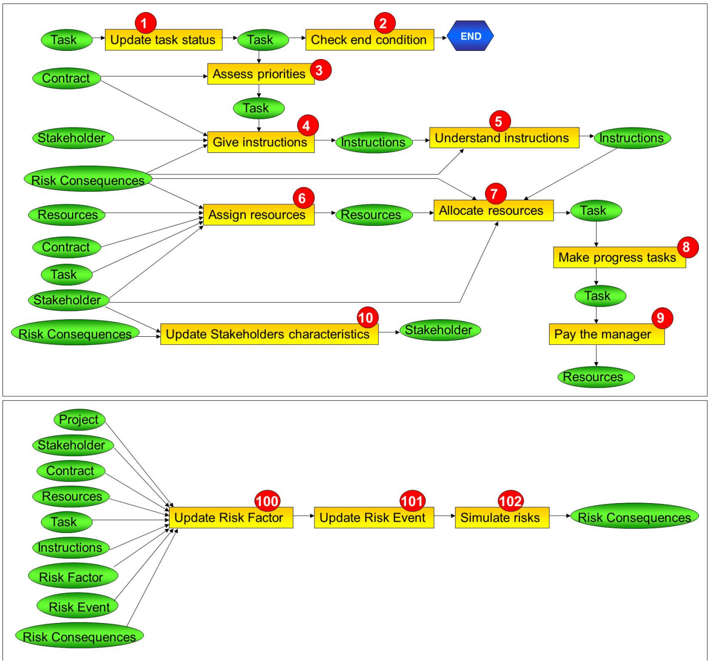

Fig. 1. Processes of the model

The model was implemented with the GAMA open-source agent-based simulation platform [12]. This platform provides a complete modeling and simulation development environment for building multi-agent simulations. Figure 2 illustrates the SMACC interface. The left screen shows the current situation of the model: in green, executable and completed task – the height of the task represents its progress; in red, the non-executable tasks; the spheres represent the stakeholder agents. The right screen monitors the project evolution (cost, time and quality) and compares it to expected values.

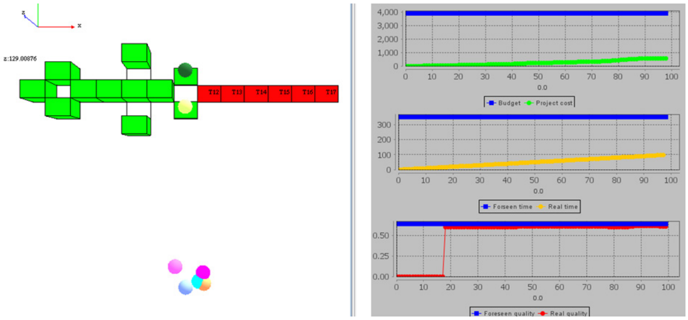

Fig. 2. Snapshot of a simulation (with the GAMA platform)

4 Application and Results

4.1 Application Case Presentation

In this section, we present an application of SMACC concerning the comparison of different risk management strategies regarding their efficiency. The application project is derived from a real public project: the construction of a nursing training institute located in South-West France. The project budget is 3.9 M€; the total time allowed to the project is 18 months (352 working days). Seven stakeholders are considered. For each of them, the initial value of motivation and expertise are set to 0.5 (mean value). Importance values were determined according to stakeholders' preferences. The project is considered at a global level, containing seventeen tasks. For each task, the needed amount of resources of each type is specified. To ensure the achievement of the project's objectives, seventeen contracts were proposed, defining for each task the demanded/requested (quality, duration and cost). 42 risk factors (difficult working conditions, bad crane installation, good communication, high security condition…) and 95 risk events were considered (work accident, difficulty to obtain building permit, underestimation of material need…). Risk events and risk factors can have beneficial (or detrimental) consequences on the project analysis and the construction company feedback. The risk event data (probability and impact) were chosen for simulation after a careful analysis of relevant literature [13-14] and risk manager experience in past similar projects.

Three strategies were simulated. The first strategy (S0) corresponds to that which would be usually chosen for the real project. The second strategy, called "safe strategy" aims at improving the safety during work by safety training and a special monitoring on this point. This strategy implies more time to perform tasks 12, 13, 14 and 15 (four tasks on working site) due to the new working conditions and training (this was simulated by adding 5% to D value for these tasks D). This strategy allows reducing the initial probability of risk events "Accident" by a factor 10. The third strategy called "High quality requirement" was proposed. In this strategy the required quality on every task was increased by 0.1. In the same time, the budget allowed to every task was increased by 10%.

4.2 Results and Discussion

In order to explore the possible solutions in the stochastic universe, Monte-Carlo simulations were performed by repeating 1000 times each strategy. Figure 3 provides the resulting distributions for quality, time and cost of the project for the three strategies.

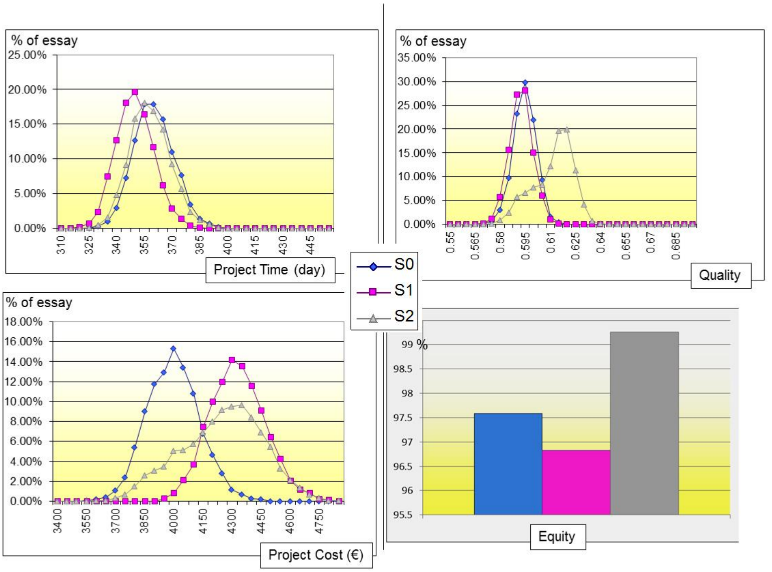

Fig. 3. Simulation results – Time, cost and quality

A fourth index was added regarding the equity between stakeholders. It is estimated by computing the percentage of stakeholders ending the project without a monetary deficit. A situation is considered as better if the equity criterion is higher. This criterion offers an additional view, which can prevent to use a strategy which would induce loser/winner situations.

The total time used by the real project was 331 working days (for 352 granted) and the budget was also respected (3.9 M€). The input data having been fitted with experts involved in the real project or similar ones, a first comparison can be carried out between the performance of the real project and those predicted by simulation using Strategy 0. It appears that the real project delay is in the lower part of the distribution curve. In fact, in the real project no serious hazard occurred, except a bad weather (important rains) during landscaping, causing a delay during this phase, but this delay was caught up during construction phases by increasing the human resources. This result is not surprising: risks are inherently stochastic and it may happen (without necessarily considering that the estimation was wrong) that the project was in an advantageous situation compared with the expected mean value. The theoretical mean value corresponds, in theory, to what could be expected in case of "many similar projects", and it is impossible to derive definitive conclusions from feedback of a single project. The real project cost is close to the mean simulation result. For the same reasons than for delay, the only possible statement is that this is not inconsistent. Quality is more difficult to analyze. An in-depth analysis would require discussion with the client to assess at what level his expectancies were satisfied by the real works.

The result shows that each of the three strategies has its advantages and drawbacks. Strategy 0 ("Standard") proposes average results on the four criteria. Strategy 1 ("High security") leads to reduce the duration of the project compared to S0 but increases the budget (4303 Vs 3972). Strategy 1 is also the worst for equity. This could be explained by the security constraints imposed to contractor (increasing the pressure on the delay). A refined analysis of the results shows that S1 increases the number of cases of budget deficit situation for the different stakeholders but limit the lost when occurred. With the two others strategies the situations of budget deficit are less common but are more important when occurred. Strategy 2 ("high quality") leads to a project cost equal to S1 and a project duration equal to S0, but this strategy allows increasing noticeably the project quality and equity. This equity increase can be explained by the increase of the budget for this strategy which allows to give to each stakeholder a margin of resources allowing to face negative events.

5 Conclusion

This paper presented an agent-based model, SMACC, to manage risk in construction projects. The main contribution of the model is its accounting of the dynamic nature of a project and of risk management. It considers at the first place the stakeholders and their capacity of reaction. This aspect, which is often not considered in classical risk analysis, is crucial. The dynamic nature of the model makes also possible to consider risk interactions, which is a significant innovation. The model was implemented on the GAMA platform and used for simulating the course of real construction projects. It allows to simulate the different possible events that could occur and the response of the stakeholders to these events. It gives a more accurate view about the possible ways the project can take. Simulations can be used to compare various project management strategies and risk mitigation processes.

SMACC has, in its present state of development, several limitations (robustness, etc.), but it already provides a significant basis for an efficient agent-based risk analysis simulation. The model will be enriched in the near future so as to better account the description of the organization of the project. Another perspective is to propose a method to generate the best strategy from user's preferences rather than just comparing different ones.

References

1. Walewski, J., Gibson, E.G.: International Project Risk Assessment: Methods, Procedures, and Critical Factors, Center Construction Industry Studies Report, 31, University of Texas, Austin (2003)

2. Carr, V., Tah, J.H.M.: A fuzzy approach to construction project risk assessment and analysis: construction project risk management system. Advances in Engineering Software 32, 847–857 (2001)
3. Anumba, C.J., Ren, Z., Thorpe, A., Ugwu, O.O., Newnham, L.: Negotiation within a Multiagent System for the Collaborative Design of Light Industrial Buildings. Advances in Engineering Software 34(7), 389–401 (2003)
4. Obonyo, E.A.: APRON: Agent-based Specification and Procurement of Construction Product. PhD Thesis, Loughborough University, UK (2004)
5. Hadikusumo, B.H.W., Petchpong, S., Charoenngam, C.: Construction material procurement using internet-based agent system. Automation in Construction 14, 736–749 (2005)
6. Li, W.: An agent-based negotiation model for the Sourcing of construction suppliers. PhD Thesis, University of Hong Kong (2008)
7. Xue, X.L., Li, X.D., Shen, Q.P., Wang, Y.W.: An agent-based framework for supply chain coordination in construction. Automation in Construction 14(3), 413–430 (2005)
8. Kim, K., Paulson, B.C.: An agent-based compensatory negotiation methodology to facilitate distributed coordination of project schedule changes. Journal of Computing in Civil Engineering 17(1), 10–18 (2003)
9. Ren, Z., Anumba, C.J., Ugwu, O.O.: Multiagent system for construction claims negotiation. Journal of Computing in Civil Engineering 17(3), 180–188 (2003)
10. Rojas, E., Mukherjee, A.: A multi-agent framework for general purpose situational simulations in the construction management domain. Journal of Computing in Civil Engineering 20(6), 1–12 (2006)
11. Kerzner, H.: Project Management: A Systems Approach to Planning, Scheduling, and Controlling, 8th edn. Wiley (2003)
12. Grignard, A., Taillandier, P., Gaudou, B., Vo, D.A., Huynh, N.Q., Drogoul, A.: GAMA 1.6: Advancing the art of complex agent-based modeling and simulation. In: Boella, G., Elkind, E., Savarimuthu, B.T.R., Dignum, F., Purvis, M.K. (eds.) PRIMA 2013. LNCS, vol. 8291, pp. 117–131. Springer, Heidelberg (2013)
13. Mehdizadeh, R.: Dynamic and multi-perspective risk management of construction projects using tailor-made Risk Breakdown Structures. PhD Thesis, Uni Bordeaux 1, France (2012)
14. Taroun, A.: Towards a better modelling and assessment of construction risk: Insights from a literature review. International Journal of Project Management 32(1), 101–115 (2014)