Optimal Reduction of Project Risk Severity: A Case Study

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ABSTRACT

Although many studies were carried out to identify the range of risky events in construction projects and the recommended response and precautionary strategies, little has addressed the means of making such decisions in an optimal way. Unfortunately, complex projects are marred with numerous interconnected causes and effects, which make project dynamics rather difficult to understand and control. A research was undertaken to optimize risk treatment in construction projects, where costs and benefits are balanced out at the project level. Study employs ant colony optimization (ACO) and dynamic risk maps (DRM) to achieve the sought research goal. This paper focuses on presenting the mechanics of the research approach via a real life case study. The construction project into consideration was executed by a well-known contractor in the Middle East. The paper first describes the case details. After the identification of project risk events, the risk inter-dependencies were modelled using a DRM, which made use of the professional knowledge of industry professionals and archived project records as well. Furthermore, ACO is utilized for the balanced selection of risk treatment strategies and to help reduce the project's overall risk severity at the minimum cost possible. Paper ends with useful insights into the research approach and outcomes of case study application.

Keywords - Optimization, Risk Management, Risk Mapping, Risk Treatment.

1. Introduction

The construction industry is known to exhibit high level of uncertainty owing to the nature of its business activities, operational environment and the project/organizational dynamics. With construction project success largely tied to the goals and results project is supposed to achieve [1], the importance of managing project risks in an efficient way has grown over the years. There is extensive literature addressing risk management in construction projects [2]; however only recently have researchers realized the need to address risk treatment in more depth [3].

An extended research was conducted by the authors to improve the decision-making process at the risk treatment stage. A major challenge was to model the inter-dependencies amongst the different risk events and the associated treatment actions. A given risk could influence and/or give rise to another. Meanwhile, some treatment actions could help address a number of risks simultaneously. The research approach adopts dynamic risk maps (DRM) and the cross impact analysis (CIA) method for inter-dependency modelling [4]. Optimizing the risk treatment actions is carried out through balancing the associated costs and benefits [5], whereas ant colony optimization (ACO) algorithm performs the actual optimization process [6]. The reader is advised to refer to the cited publications for further information about the complete research approach by the authors.

The paper at hand tries to shed more light on the practical aspects of the research approach via applying onto a real life case study. The project in reference is a huge industrial pipeline in Saudi Arabia executed by a well-known construction contractor. After reviewing the main characteristics of the studied case, the paper goes about identifying project risks, modelling the risk inter-dependencies via a DRM, employing ACO for the comparison and balanced selection of risk treatment strategies with an aim of reducing the project's overall risk severity.

2. Case Description

The case in reference comprises the engineering and construction of a 1000 KM pipeline that extends from an industrial facility till a terminal station. The project is an addition to a huge existing plant located in an industrial city. The works also include the construction of a marine terminal at the pipeline's endpoint. But, the terminal station works are assigned to a subcontractor and not part of the specific scope addressed in this paper.

The pipeline project is contracted on a Design and Build lump sum basis between the client, being the local government, and an international construction contractor operating in Saudi Arabia. The contractual project duration is set at twenty four months.

The contractor for the job has a mature project management system that is well-connected to the company's global management system. Also, it has a capable in-house team in Saudi Arabia that can handle and develop customized solutions for unexpected project scenarios. It is also worth mentioning that the contractor is simultaneously involved in other parallel projects inside the industrial plant itself.

As for the pipeline, which is the main focus of the paper, the route has limited accessibility at certain sections but not all. Furthermore a good mix of local and international subcontractors is involved in the piping works.

3. Risk Identification

According to the literature, risk identification involves examining all sources of risk not only from the perspective of the organization concerned, but also from the perspective of other stakeholders, external as well as internal. It is important to identify each source of risk so that an analysis can be made later of the likelihood, consequence and importance of that risk. Different types of risks may fall under more than one of the categories developed for the classification of risk [7, 8]. While some recommend that the risk identification process should stop short of assessing or analyzing risks so that it does not inhibit the identification of "minor" risks. In practice, however, risk identification and assessment are often completed in a single step [9].

As part of the regular risk planning for the pipeline project, a complete Risk Register was developed and maintained by the project team. To demonstrate the functioning of the research approach, the top risks in the risk register, i.e. those evaluated as Extreme (E) or High (H) were extracted as illustrated in table 1. It is considered that these risks are the significant risks in the project as per the perception of the project team.

4. DRM-Based Quantitative Analysis

The risk severity perceived in the previous step does not account for the inter-dependencies amongst the different risks. Each risk was evaluated independently from the others. This necessitates a better understanding and modeling of these inter-dependencies to more accurately evaluate the project risks. DRMs are simply used to achieve the sought results. As known, quantitative risk analysis attempts to numerically estimate the probability that a project will meet its cost and time objectives. Quantitative analysis is based on a simultaneous evaluation of the impact of all identified risks. The result is a probability distribution of the project's cost and completion date based on the risks in the project [10]. When used with the CIA capabilities, the DRM becomes a capable tool for evaluating the overall project risk dimension. In this context, the CIA method performs the computations and reasoning operations [4].

Table1. Identified Risks in the Pipeline Project

Risk ID	Risk Description	Risk Severity
R1	Competing project utilizes planned right of way, resulting in a need to adjust route	2.8 (E)
R2	Identified site for storage/disposal of extracted material for terminal site not suitable due to volume/type of material	2.8 (E)
R3	Future expansion plans unknown which could be limited if attempted after initial terminal in operation	2.8 (E)
R4	Operability and Maintenance review of terminal has not been completed which results in misalignment between O&M and design teams	2.1 (E)
R5	Other projects competing for construction material and resources	2.1 (E)
R6	Lack of resources to complete entire regulatory phase of the project due to budget reductions	2.1 (E)
R7	Lack of understanding of effort to construct instep slopes and rock	2.0 (E)
R8	Ongoing revisions to the project description result in invalid/inadequate environmental assessment/stakeholder relations	2.0 (E)
R9	Line rupture impacts environment / parallel pipeline /else	1.5 (H)
R10	Schedule slippage during regulatory phase because it is beyond of project control	1.5 (H)
R11	Remote areas limit access for emergency evacuation during construction results in escalation of injury	1.5 (H)
R12	Safety of personnel during construction	1.5 (H)
R13	Regulators require that pipeline corridor be established based on previous projects resulting in route changes	1.5 (H)
R14	Integrity of the pipeline impacted due to Constructability/operability challenges (routing, slopes, crossings, etc.)	1.5 (H)

The risk owners for the fourteen identified risks, as per table 1, were chosen for the mapping process that took place in a risk analysis workshop. To elicit their feedback, the 14 risks were listed both horizontally and vertically in a tabular form. Risk owners were asked to tick any existing dependency relationship between the identified risks on the table in reference.

To better represent the potential impact in a given dependency relationship, a significance scale between “zero” and “three” was employed [11], where 3 is representing a significant relationship in the same direction (S+), 2 is representing a moderate relationship in the same direction (M+), 1 is representing a slight relationship in the same direction (L+), whereas zero means no relationship. Figure 1 illustrates the immediate relations between the risk factors according to the outcomes of the risk analysis workshop.

As seen, there are 19 inter-dependency relationships between the 14 identified risks. This is broken down into eight significant-influence relationships, five moderate-influence relationships, and six slight-influence relationships. According to the principles of CIA, the significance/severity of a certain risk can change because of the inter-dependency with all associated risks compared with the stand-alone evaluation. Simply, the probability of risk occurrence, and thus its significance, increases due to the accumulated effects of the associated risks. Note that how much influence is depicted through the ordinal scale above and as illustrated in figure 1.

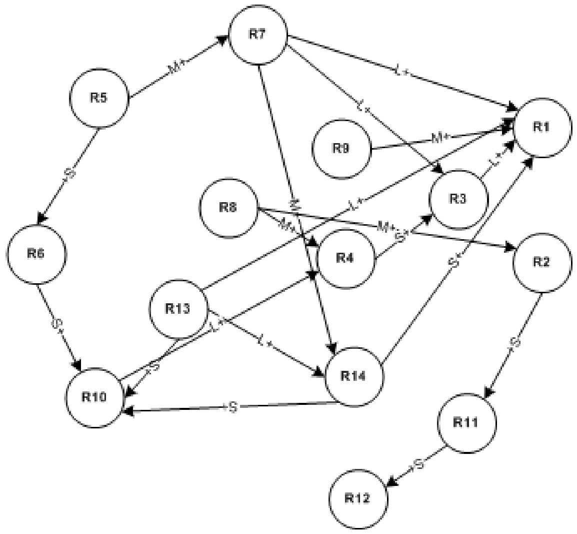

Figure1. DRM for the Significant Risk Factors in the Studied Case.

Table 2 shows the re-ordering of the various risks after running the calculation based on the DRM and the principles of CIA. As can be seen the posterior severity increases beyond the prior severity, which only accounts for individual risks with no accumulated effects. Further details on running the calculations can be found in Zabel et al. [4].

Table 2. Comparison between Initial and Posterior Severity of Identified Risks

Rank	Risk	Initial Severity	Posterior Severity
1	R1	2.8	3.6
2	R3	2.8	3.6
3	R2	2.8	3.5
4	R6	2.1	2.7
5	R4	2.1	2.6
6	R10	1.5	2.4
7	R11	1.5	2.4
8	R12	1.5	2.4
9	R14	1.5	2.3
10	R5	2.1	2.1
11	R7	2.0	2.0
12	R8	2.0	2.0
13	R9	1.5	2.0
14	R13	1.5	1.5

5. Risk Treatment

Risk treatment is the process of selecting and implementing measures to modify the risk [12]. Risk treatment encompasses what will be done in response to the identified project risks, with the ultimate goal of reducing the project’s overall risk exposure [13]. On other hand it should be mentioned that it isn't always possible to eliminate all kinds of risk from a project [14]. Unless actions are taken, the entire risk identification and assessment process would be a waste. Consequent to identifying and analysing project risks, the research method proceeds to:

- Identify the potential risk treatment actions.
- Use indices to estimate the cost and benefit for each risk treatment action. The indices can utilize either quantitative or qualitative data.
- Optimize the risk treatment actions via minimizing the project’s risk exposure in the most cost effective manner.

Table 3 outlines a set of risk treatment actions with potential for handling the 14 risks identified in the earlier stage. The risk treatment actions are classified into five levels according to the actual cost of performing these actions. In this context, level one corresponds to the lowest cost, level five corresponds to the highest cost, with levels two, three, four in-between. This is denoted by the Cost Index (CI) in table 3.

Table 3. Risk Treatment Actions

Code	Description	CI
T1	Developing a monitor system for the competing projects with potential impact on the pipeline project	2
T2	Early planning, including mobilization, resource management, etc., to be combined with strategy	3
T3	Developing an efficient communication plan to ensure a positive cooperation and coordination throughout all project stages	5
T4	Developing a program for training; skills shall be upgraded and refreshed	3
T5	Sign fixed/predefined prices with material suppliers	4
T6	Developing resource management system to identify and control resources	3
T7	Developing change management system	1
T8	Re-adjust the project plan	1
T9	Use more advanced equipment	5
T10	Re-develop or modify the design	5
T11	Hire a consultant for design review	3
T12	Increase the supervision staff	2

Each risk treatment action is perceived to associate with one or more risks. It is fundamental at this stage to map the treatment actions to the 14 identified risks. Another mission is to assess the extent to which each treatment action contributes to the mitigation/treatment of the associated risks. To simplify the process, a percentage of severity reduction is utilized. Figure 2 illustrates, in a matrix form, the percentage of severity reduction for each treatment action in relation to a given risk.

	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	**R13**	**R14**
T1	80%		10%		70%	40%		30%		10%				
T2	10%	70%	40%		30%		40%							
T3	40%		80%		30%		40%		30%				30%	
T4				30%			70%					50%		
T5						40%				50%				
T6						30%				40%				
T7	50%		70%											10%
T8	30%				10%	40%				50%				
T9		30%								40%	30%			
T10	40%		30%	30%										
T11	70%		80%	80%										
T12				70%			40%			80%				

Figure 2. Severity Reduction Matrix

6. ACO Application

Optimizing the risk treatment in a project involves identifying the actions with the highest benefit-cost (B/C) balance to that project. A risk treatment index, I_{RT}, is devised to measure the B/C balance, as follows:

$$I_{RT} = (P_b I_b * (P_b I_b - P_a I_a)) / C_{RT} \qquad (1)$$

where P_b is the probability of risk occurrence prior to applying the risk treatment action, I_b is the risk impact prior to applying the risk treatment action, P_a is the probability of risk occurrence after applying the risk treatment action, I_a is the risk impact after applying the risk treatment action, and C_{RT} is the cost associated with the risk treatment action. As noted, the B/C ratio is multiplied by the term $P_b I_b$ so as to factor in the relative significance of the project risks, which is a fundamental aspect in the succeeding optimization process.

The research employs ACO [15, 16, 17] to reach the optimal strategy for reducing the project's risk severity. Full details of the optimization process developed by the authors can be found in Georgy et al. [5] and Zabel et al. [6]. Figure 3 summarizes the optimization process as per the ACO principles till reaching the optimum solution sought.

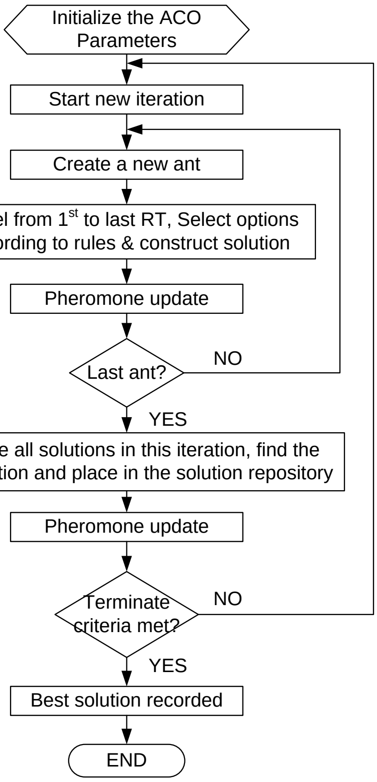

Figure 3. ACO Process for Risk Treatment Optimization

As shown in figure 3, treatment actions are modelled as the problem's decision variables. Ants representing the decision variables are initiated with certain pheromone values. Based on the selection process that is part of ACO, the pheromone values are updated. The algorithm loops back for more iterations until the stopping condition is met; that is the number of iterations in this research.

The pipeline case study involves 14 significant risk factors with summed severity value of 35.1. This is obtained by summing up the posterior severity values for individual risks in table 2. On the other hand, there are 12 potential treatment actions in place. Decision-maker envisions that a reduction of about one third of the existing severity is desirable. As a result it was sought to reduce the risk severity by 35% at the least cost possible.

To reach the optimum set of risk treatment actions, the process starts with initializing the ants and optimization parameters, e.g., pheromone values. Process follows as per the steps in figure 3. A number of ants/solutions are created, each of which represents a scenario of risk treatment option(s). When considering the case study, the total number of permutations, i.e., possible options for project risk treatment, is 5.6×10^{13}. Table 4 captures the iteration variables, including, iteration number (#), trip path (TP), post-optimization risk severity (S_{post}), percentage of severity reduction (%Red), and the total cost index for the set of treatment actions into consideration (TCI).

Table 4 Extract from the Optimization Results

#	TP	S_{post}	% Red	TCI
1	T1	30	14.5%	2
2	T2	31.2	11.1%	3
3	T3	31.4	10.5%	5
.	.		.	.
.	.		.	.
.	.		.	.
13	T1, T2	26.8	23.6%	5
14	T1, T3	27.1	22.8%	7
15	T1, T4	28.8	17.9%	5
.	.		.	.
.	.		.	.
.	.		.	.
95	T1, T2, T7, T12	21.4	39%	8
.	.		.	.
.	.		.	.
.	.		.	.

The results show that the optimum risk treatment scenario needed to achieve a reduction of 35% comprises the actions T1, T2, T7 and T12. These options allow reducing the risk severity as required by the decision-maker while achieving such goal at the least cost possible.

It is quite important to differentiate between the existing project controls and the instated risk treatment actions. For instance, in the pipeline project under study, treatment action T1 comprises the development of a monitoring system for competing projects with a potential to impact the pipeline project under study. It is understandable that both the studied and competing projects do have their own control and management systems; however the treatment action T1 requests the contractor for the pipeline project to establish and tailor a monitoring system to specifically address the cross-project impacts. The latter is over and above the management system in place. The cross-project monitoring system aims to watch for the competing projects particularly the nearby ones, identify potential conflicts or substantially negative impacts from any of those projects, and provide the means to take necessary actions in due time.

T1 implementation also helps in decreasing the overall external uncertainty of the studied pipeline project thereby decreasing the severity of risk R1. For the long run, such action can further contribute to better insights into future expansion plans of the industrial plant/complex. Records of cross-project impacts and conflicts that eventuated can prove very useful for all future risk planning efforts.

The risk treatment action T2 comprises the early planning for mobilization and resource management at strategy setting. In addition to the regular project plan and work schedule, a more comprehensive and detailed plan for the mobilization phase and resource assignment at the project's early stage is required.

T2 implementation enhances the efficient design of storage/disposal areas, improves the construction of instep slopes and rocks, in addition to reducing the line rupture impacts on the environment and other pipeline systems. Like T1, with good understanding of the material and other resource requirements, the T2 action can provide better coordination amongst all ongoing projects and better long term planning.

The risk treatment action T7 comprises the development of an efficient change management system. While the contractor for the pipeline project possessed a change control and management system, room for improvement was detected. Finally, risk treatment action T12 comprises increasing the supervision staff for the pipeline project along with the internal review and auditing processes. Purpose is to mitigate the misalignment between the operation and maintenance (O&M) and design teams. Also, T12 implementation can help improve the overall project control, reduce schedule slippage occurrences, and improve usage of resources and reduction of waste.

7. Conclusions

Recently, there has been a renewed research interest in the treatment stage of the risk management process. It is true that without properly responding to project risks, all efforts to identify and assess them will be turn futile.

This paper presents part of a research by the authors to optimize the risk treatment in construction projects. However this is by no means an easy task. Construction projects are complex systems with many inter-dependencies amongst the risk events and their triggers. Moreover, there are diverse options to responding to project risks. One has to consider all permutations while trying to get the most benefits out of the monies invested.

The research approach combines DRM, CIA, and ACO for achieving the research goal. The primary focus of the paper was to exemplify the research approach in a real construction project. Details of the research approach can be found in earlier publications by the authors [4, 5, 6]. The case study itself is a sizable pipeline project in Saudi Arabia that extends between an existing plant and terminal station.

Applying ACO proved particularly useful given the number of permutations present. ACO is classified under the so-called "evolutionary algorithms". These algorithms are more capable of handling the more complex optimization problems where the traditional approaches do not fare as well or become impossible to apply, e.g., case of NP-hard problems.

The particular goal established for the case study was to reduce the risk severity by approximately one third at the least cost possible. The research approach can handle both qualitative and quantitative data. However it is known that the quantitative data is usually hard to get by. This is a major strength of the research approach since it can still function using numerical scales. The particular scenario selected for the case study in paper was to adopt 4 or the potential 12 risk response strategies.

While the research approach and exemplification showed its potential in a practical application, there remains the challenge of industry adoption. Industry practitioners are usually reluctant to incorporate such platforms and tools in project management processes. However, through multiple examples of real life projects, such as the one in this paper, a more convincing case can be established. This might lead to less reluctance to adopting such platforms and tools in future.

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