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ASSESSMENT OF PROJECT RISKS IN FAST-TRACK CONSTRUCTION PROJECTS: AN EVALUATION OF RISK MITIGATION RESPONSES

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Abstract: The goal of this study is to introduce a risk mitigation approach applied to fast-track projects as the last phase of a risk assessment framework for fast-track construction projects. The research investigates risks that might arise from different levels of overlapping. But specific studies of risk mitigation when construction project activities are overlapped has not been well explored. This study aims to (1) quantify the ability of the risk responses to mitigate the risks and the overall impact on the project target performance metrics, and (2) determine the optimal combination of the risk mitigation responses that would minimize the project risk exposure and the mitigation costs. The conceptual model developed applied Monte Carlo simulation, optimization, and Pareto Front analysis. The goal was to assess the risk mitigation responses and find the optimal combination of the risk responses to minimize the mitigation costs and maximize a potential contractual bonus. The results showed that an evaluation of the risk mitigation responses can give objective information about the potential reduction in project risk exposure. In this conceptual case, the planned risk responses applied would not be sufficient to promote a significant change in the project risk exposure. However, it would be possible to obtain an overlapping combination that could produce a satisfactory bonus-risk mitigation cost trade-off, meaning that it might be worthy to expend financial resources and try to mitigate the risks that can compromise the fast-track strategy of the project.

1 INTRODUCTION

The construction industry is known as risky and complex. However, regardless of the current complexity in construction projects, the construction industry has responded to calls for reduced project delivery times to meet regulatory obligations, emergency/disaster recovery, and time-to-market limitations. Approaches such as activity crashing, activity overlapping, and activity substitution can be used under the need to compress the traditional project schedule. Projects that apply activity overlapping technique in their schedules are called fast-track projects.

Despite the inherently risky characteristics of the construction industry, fast-track projects might be subjected to unique risks or risk characteristics arising from the overlapping of activities that can affect the project duration and cost, threatening the fast-track strategy. Therefore, the relation between activity overlapping and risk must be understood to achieve a better risk management approach to fast-track projects avoiding threats to the project duration and cost.

Recent research about fast-track, overlapping, and concurrent engineering focused on aspects of contract and partnership, fast-track best practices, fast-track predictability, optimization of the project duration, time-cost trade-off, and the impact of the rework. Some studies have been carried out on the aspects of contract and partnership, best practices, and objectives predictability in fast-track projects (Gerk and Qassim 2008; Kyuman Cho and Hastak 2013; Hazini, Dehghan, and Ruwanpura 2014; Dehghan, Hazini, and Ruwanpura 2015; Abuwarda and Hegazy 2016; Gwak et al. 2016; K. Cho et al. 2009; Moazzami, Dehghan, and Ruwanpura 2011; Deshpande, Salem, and Miller 2012; Bogus et al. 2011).

Risk mitigation and response are an integral part of a risk management process. Planning and evaluating risk mitigation responses closes the risk management process or cycle (Project Management Institute 2013). The objective of a risk response phase is to define responses to the identified risks that can avoid, transfer, mitigate or accept the risk (Project Management Institute 2013). The risk response plan can also include a contingency plan with reactive responses that are executed if specific risk trigger events occur, however, the analysis of contingency responses is out of the scope of this research. Risk mitigation has been investigated in the construction areas of green building, transportation, contract management, project complexity, and safety and health to name a few (Hallowell and Gambatese 2009; Jasper Mbachu and Samuel Taylor 2014; Zhang and Fan 2014; Fan, Li, and Zhang 2015; Qazi et al. 2016; Bon-Gang Hwang et al. 2017).

Therefore, the purpose of this study is to answer the question “How should we mitigate the risk of overlapping over time and determine the optimum combination of risk responses that would minimize risks and minimize the mitigation cost?”. The following objectives will be achieved trying to answer this question: (1) to quantify the ability of the risk responses/strategies to mitigate the risks and the overall impact on the project target performance metrics and (2) determine the impact boundaries of the risks and the optimal combination of the risk responses or strategies. In order to attain the aforementioned objective, an assessment of the impact of these strategies on the project performance metrics will be performed running a conceptual model. The model was developed using Monte Carlo simulation and optimization formulation to finally apply a Pareto Front to obtain the optimal combination of mitigation responses/strategies to maximize the positive impact on the target performance metrics.

2 METHODOLOGY

The methodology of this study comprises three main steps. The first step is the problem formulation where the variables and parameters of the model are defined and calculated. The second step is the simulation model running a Monte Carlo simulation to quantify the ability of the risk responses to mitigate the risks and influence the project performance metrics (e.g., project duration, project cost). The last step is the optimization and the Pareto Front to find an optimal combination of the mitigation responses. The proposed framework for the conceptual model is shown in Figure 1.

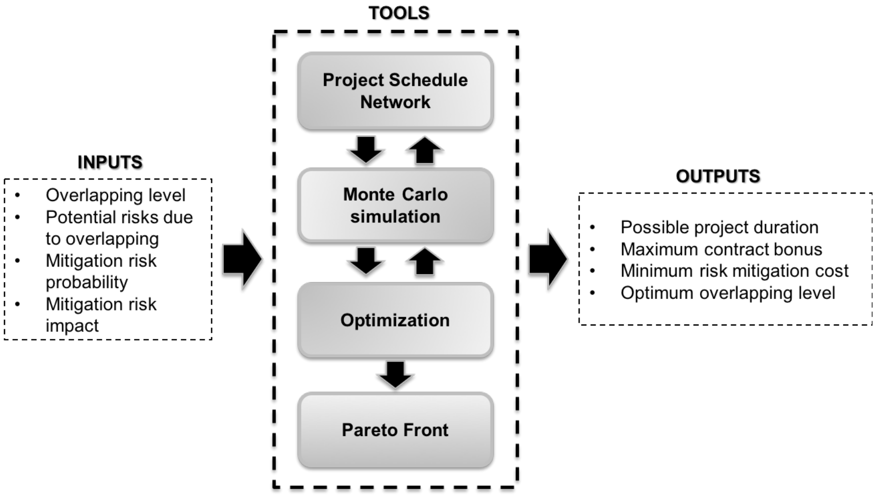


Figure 1: Risk mitigation conceptual model framework

2.1 Problem formulation

The model of this study was based in the model developed by Garrido Martins et al (2017). The project schedule network considers the variables activity duration, overlapping level (lag), activity early start, and activity early finish. A traditional schedule relationship of finish-to-start was used to build the relationship logic. In the formulas below, the index i represents an activity and the index p is its predecessor activity.

The activity duration d_i (Eq. 1) represents the expected time, in days, to complete the activity without the impact of any overlapping risk. The overlapping level OL_ip (Eq. 2) refers to the percent amount of time that a successor activity will start before the predecessor activity finishes. This study considered three overlapping levels 25% (low), 50% (medium), and 75% (high). These overlapping level values were defined according to the overlapping framework proposed by Peña-Mora and Li (2001). Therefore, the amount of overlapping O_ip, in days, between predecessor and successor activities is related to the duration of the predecessor activity and can be calculated (Eq. 3).

[1] d_i ∀ i = 1,…,N

[2] OL_ip ∈ {0.25, 0.50, 0.75} ∀ i = 1,…,N; p = 1,…,N; p = i - 1

[3] O_ip = d_p · OL_ip ∀ i = 1,…,N; p = 1,…,N; p = i - 1

The activity early start (ES_i) (Eq. 4) represents the expected earliest time that the activity can start. In a Critical Path Method (CPM) network logic, the start of an activity depends on the type of activity relationship applied. A constraint was applied to ES_i to guarantee that the successor activity will not finish before its predecessor activity; it will only finish later or at the same time. The final ES_i value is rounded up to avoid values that represent partial days. Finally, the activity early finish (EF_i) (Eq. 5) represents the expected earliest time that the activity can finish, according to its expected duration and start time. The early finish of the successor activity EF_i must be equal to or greater than the early finish of the predecessor activity (EF_p) (Eq. 6).

[4] ES_i = Round up EF_p – O_ip + di, EF_p – O_ip + d_i ≥ EF_p
EF_p – d_i , otherwise ∀ i = 1,…,N; p = 1,…,N; p = i – 1

[5] EF_i = ES_i + d_i ∀ i = 1,…,N

[6] EF_i ≥ EF_p ∀ i = 1,…,N; p = 1,…,N; p = i - 1

The risk parameters are represented by the variables risk probability of occurrence, risk impact, risk frequency, and total risk impact. This study considers only the potential risks that can arise due to activity overlapping. The conceptual risk mitigation model used hypothetical risks and few examples can be found in the literature, such as construction site space constraints and equipment allocation problems, to name a few (Gündüz et al. 2013). The study considered that the risk factors can vary for each level of overlapping, hence a value of probability of occurrence and a value of impact were defined for each level of overlapping. Therefore, the risk probability of occurrence (P_i) (Eq. 7) represents the likelihood of a risk event occurring. The risk impact (I_i) (Eq. 8) is the impact, in days, on the schedule caused by the occurrence of the risk. A PERT distribution was used to calculate the risk impact (Eq. 9). The risk occurrence probability and the risk impact are also associated with risk with a planned mitigation action. In this case, the new probability of occurrence and the new risk impact after a mitigation action are represented by P_i(mitigation) and I_i(mitigation) respectively. Hence, P_i(mitigation) and I_i(mitigation) are formulated in the same way as P_i and I_i, respectively. This conceptual model used hypothetical mitigation actions to demonstrate the method, however, examples of mitigation actions can include the increase in the number of specific workers, allocation of more experienced workers, or rental alternatives in the case of equipment failure.

[7] P_i = P_(low)_i, OL_ip = 0.25
P_(medium)_i, OL_ip = 0.50

P_(high)_i,   OL_ip = 0.75   ∀ i = 1,…,N; 0 < P_i < 1

[8] I_i = I_(low)_i,   OL_ip = 0.25

I_(medium)_i,   OL_ip = 0.50

I_(high)_i,   OL_ip = 0.75   ∀ i = 1,…,N

[9] I_(OL)_i = Round up [(I_(OL)_optimistic_i + 4 · I_(OL)_most likely_i + I_(OL)_pessimistic_i)/6]   ∀ OL = {low, medium, high}; i = 1,…,N

The risk frequency (F_i) (Eq. 10) defines the occurrence or non-occurrence of the risk. A binomial distribution was used to calculate the risk frequency (Eq. 11). Lastly, the total risk impact (RI) that affects the duration of an activity is represented by the sum of the impact of all risks that occurred for a specific activity (Eq. 12).

[10] F_i ∈ {0,1}   ∀ i = 1,…,N

[11] F_i = 1_C_x · (P_i)^x · (1 – P_i)^(1-x)   ∀ i = 1,…,N; 0 ≤ x ≤ 1; x = discrete integers

[12] RI = ∑ (F_i · I_i)   ∀ i = 1,…,N

Hence, after the definition of the total risk impact, the activity early finish (EF_i) can be redefined to consider the total risk impact (RI) on the activity duration (Eq. 13).

[13] EF_i = ES_i + (d_i + RI)   ∀ i = 1,…,N

Finally, the outputs will be produced from the results of the simulation. The outputs are the project schedule duration (SD) (Eq. 14), a possible contract bonus to finish the project earlier (B) (Eq. 15) and a total risk mitigation cost (CM) (Eq. 16).

[15] SD = ES_1 + ∑(d_i + RI) - ∑[(d_p + RI) · OL_ip]   ∀ i = 1,…,N; p = 1,…,N; p = i - 1

[15] B = (SD_t – SD_o) · b   ∀ SD_t = project target duration, SD_o = duration with overlapping and no risk occurrence, b = bonus value per day in dollars

[16] CM = (SD_or – SD_o) · cm   ∀ SD_or = project duration with overlapping and risk occurrence, cm = cost of risk mitigation per day in dollars.

2.2 Simulation model

The model was developed using commercial software that includes a Monte Carlo simulation module and the ability to work with the input variables as distributions. The conceptual simulation model reproduced the conceptual case study schedule. The assumption of this model was that all activities could be overlapped, except the first and the last activities. A constraint was imposed, where the successor activity could not finish before the predecessor activity. Moreover, each risk was associated with only one activity. In addition, the new estimated values for the probability of occurrence and impact obtained from the mitigation action will substitute the original values originally used to run the model without mitigation.

The initial overlapping level for each link was set up to zero (no overlapping). The Monte Carlo simulation was set up to run using Latin Hypercube sampling and with an automatic number of iterations sufficient to achieve results with a convergence tolerance of 1% and 95% confidence level. The simulation stops when the parameters of convergence and confidence level are reached.

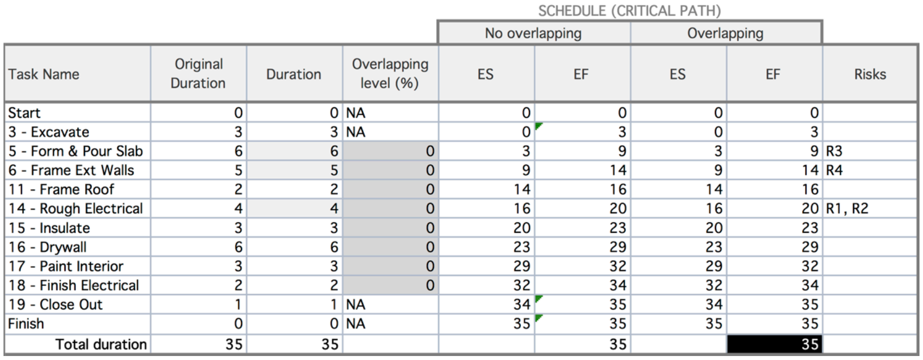
The outputs from the Monte Carlo simulation include the probability of attaining the desired fast-track project duration under different risk scenarios, the most probable duration of the project, the most significant risks, and the activities most affected by the risks. A comparison of the results obtained without the mitigation actions was done. The comparison results give to decision-makers a better idea of how much the risk responses affect the performance metrics of the project (e.g. project duration, project cost) and can assist in the decision-making process.

2.3 Optimization

The optimization process to obtain the optimal level of overlapping for each activity with the minimum project duration was slightly adjusted from the simulation model to run the optimization process. During the optimization process, a number of trial solutions were generated using Monte Carlo simulation and the OptQuest Engine as the optimization method that combines Tabu search, scatter search, integer programming, and neural networks into a single, composite search algorithm. The optimization model was set up to run 10,000 trials and use Latin Hypercube sampling. The simulation was automatically stopped at 6,562 trials because the best solution was found. The second part of the optimization process consisted of a code developed to load the output data of the first part of the optimization process and perform a Pareto Front between the potential total contract bonus versus total risk mitigation cost to find the optimum trade-off, minimizing the mitigation cost and maximizing the project bonus.

3 CONCEPTUAL CASE STUDY

The conceptual case study was the project example produced by Newitt (2009) and used in Garrido Martins et al. (2017). Figure 2 shows the conceptual case study schedule. The original duration without overlapping was 35 days. For the purpose of demonstrating the methodology, only the critical path containing 10 activities was used. This way, overlapping was defined to occur in 8 activities. In this conceptual project, three activities could be impacted by a hypothetical risk and one of them had two risks associated. Moreover, two risk response actions to respond to risks R1 and R2 were considered.



				SCHEDULE (CRITICAL PATH)				
				No overlapping		Overlapping		
Task Name	Original Duration	Duration	Overlapping level (%)	ES	EF	ES	EF	Risks
Start	0	0	NA	0	0	0	0	
3 - Excavate	3	3	NA	0	3	0	3	
5 - Form & Pour Slab	6	6	0	3	9	3	9	R3
6 - Frame Ext Walls	5	5	0	9	14	9	14	R4
11 - Frame Roof	2	2	0	14	16	14	16	
14 - Rough Electrical	4	4	0	16	20	16	20	R1, R2
15 - Insulate	3	3	0	20	23	20	23	
16 - Drywall	6	6	0	23	29	23	29	
17 - Paint Interior	3	3	0	29	32	29	32	
18 - Finish Electrical	2	2	0	32	34	32	34	
19 - Close Out	1	1	NA	34	35	34	35	
Finish	0	0	NA	35	35	35	35	
Total duration	35	35			35		35	

Figure 2: Conceptual case study schedule

Table 1 contains the risk parameters of the probability of occurrence and impact used in this simulation. The values are synthetic data created for the purpose of demonstrating the methodology. The rows identified by R1, R2, R3, and R4 contain the original parameter values for each of the risks. The rows identified Resp. contain the new parameters values for R1 and R2, respectively, considering the risk response actions. The changes for each value are highlighted. In this case, the mitigation response applied to R1 would reduce the probability of occurrence for the medium (50%) and high (75%) levels of overlapping. The reduction in the impact was also applied to the medium and high level of overlapping. The mitigation response applied to R2 would reduce the probability of occurrence in all levels of overlapping and the impact for the low (25%) and medium levels of overlapping.

Lastly, the dollar values for the project bonus and the mitigation cost were allocated at a flat rate per day. The bonus value was estimated at $ 5,000 per day and the mitigation cost at $ 4,000 per day.

Table 1: Risk parameters

	Probability per Overlapping Level			Impact per Overlapping Level (PERT)* (days)								
				Low (25%)			Medium (50%)			High (75%)		
	L	**M**	**H**	**O**	**ML**	**P**	**O**	**ML**	**P**	**O**	**ML**	**P**
R1	0.05	0.2	0.5	10	20	30	15	30	40	17	34	45
Resp	0.05	0.1	0.3	10	20	30	13	25	38	16	30	40
R2	0.1	0.1	0.2	5	8	15	5	8	15	9	14	26
Resp	0	0.05	0.1	3	5	10	4	7	15	9	14	26
R3	0.3	0.4	0.6	7	12	20	9	16	26	11	18	30
R4	0.6	0.7	0.8	6	12	24	7	14	28	8	18	34

*Legend: L = low, M = medium, H = high; O = optimistic, ML = Most likely, P = pessimistic, Resp. = risk response value

4 ANALYSIS

The summary statistics for the Monte Carlo simulation are shown in Table 2 and the probability distribution of the total duration of the project is shown in Figure 3. The results of the simulation show that after the risk response actions to the risks R1 and R2, the project risk exposure decreased. Lower values were obtained for maximum duration (from 111 to 108), mean (from 47.6 to 42.9), standard deviation (from 17 to 14), variance (from 291 to 190), and median (from 44 to 41). However, the most probable duration represented by the model remained the same, 38 days, higher the traditional duration of 35 days. The probability chance of finishing the project in less than 35 days increased from 21.4% to 26.5%, therefore it still had a high chance of 73.5% to finish the project later.

Table 2: Summary Statistics for the Total Duration

Summary Statistics for Total duration (days)		
Statistics	Before mitigation	After mitigation
Minimum	16	17
Maximum	111	108
Mean	47.6	42.9
Std Dev	17	14
Variance	291	190
Median	44	41
Mode	38	38

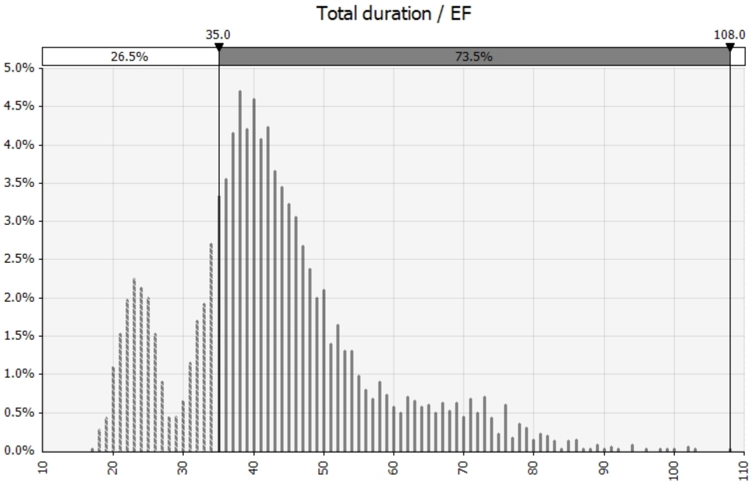


Figure 3: Total Duration (days) Probability Distribution

During the optimization process, the simulation produced 6,562 different results that were loaded to create the Pareto Front. The Pareto Front method between bonus and risk mitigation cost produced 26 points. In Table 3 and Table 4 each column identified from 1 to 26 represents one of the 26 points. For each point, the overlapping level combination is showed along with the resulted project duration with and without the occurrence of risks. The overlapping level is in percent and the duration in days.

Table 3: Overlapping combination and duration for the Pareto front points (1 to 13)

	Pareto Front points												
Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Start	0	0	0	0	0	0	0	0	0	0	0	0	0
3 - Excavate	0	0	0	0	0	0	0	0	0	0	0	0	0
5 - Form & Pour Slab	25	25	25	25	25	25	25	25	25	25	25	25	25
6 - Frame Ext Walls	75	75	75	75	75	75	75	75	75	75	75	75	75
11 - Frame Roof	75	75	75	75	50	50	50	50	25	25	25	25	25
14 - Rough Electrical	75	75	50	50	75	75	50	50	75	75	75	75	75
15 - Insulate	75	75	75	75	75	75	75	75	75	75	75	75	75
16 - Drywall	75	75	75	75	75	75	75	75	75	75	75	75	50
17 - Paint Interior	75	50	75	50	75	50	75	50	75	75	50	50	75
18 - Finish Electrical	75	75	75	75	75	75	75	75	75	50	75	50	75
19 - Close Out	0	0	0	0	0	0	0	0	0	0	0	0	0
Finish	0	0	0	0	0	0	0	0	0	0	0	0	0
duration without risks (days)	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**19**	**20**	**19**	**20**	**20**
duration with risks (days)	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**38**	**37**	**38**	**38**

Table 4: Overlapping combination and duration for the Pareto front points (14 to 26)

	Pareto Front points (cont.)												
Task	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Start	0	0	0	0	0	**0**	0	0	0	0	0	0	0
3 - Excavate	0	0	0	0	0	**0**	0	0	0	0	0	0	0
5 - Form & Pour Slab	25	25	25	25	25	**25**	25	25	25	25	25	25	25
6 - Frame Ext Walls	75	75	75	75	75	**75**	75	75	75	75	75	75	75
11 - Frame Roof	25	25	25	25	25	**25**	25	25	25	25	25	25	25
14 - Rough Electrical	75	75	75	50	50	**50**	50	50	50	50	50	25	25
15 - Insulate	75	50	50	75	75	**75**	75	75	75	50	50	75	75
16 - Drywall	50	75	75	75	75	**75**	75	50	50	75	75	75	75
17 - Paint Interior	50	75	50	75	75	**50**	50	75	50	75	50	75	50
18 - Finish Electrical	75	75	75	75	50	**75**	50	75	75	75	75	75	75
19 - Close Out	0	0	0	0	0	**0**	0	0	0	0	0	0	0
Finish	0	0	0	0	0	**0**	0	0	0	0	0	0	0
duration without risks (days)	**20**	**20**	**20**	**19**	**20**	**19**	**20**	**20**	**20**	**20**	**20**	**20**	**20**
duration with risks (days)	**38**	**38**	**38**	**37**	**38**	**37**	**38**	**38**	**38**	**38**	**38**	**38**	**38**

The plot with all the points resulted from the simulation run, the Pareto Front, and the optimum point is showed in Figure 4. The values for the potential total bonus and the mitigation cost were calculated using Equation 15 and Equation 16, respectively.

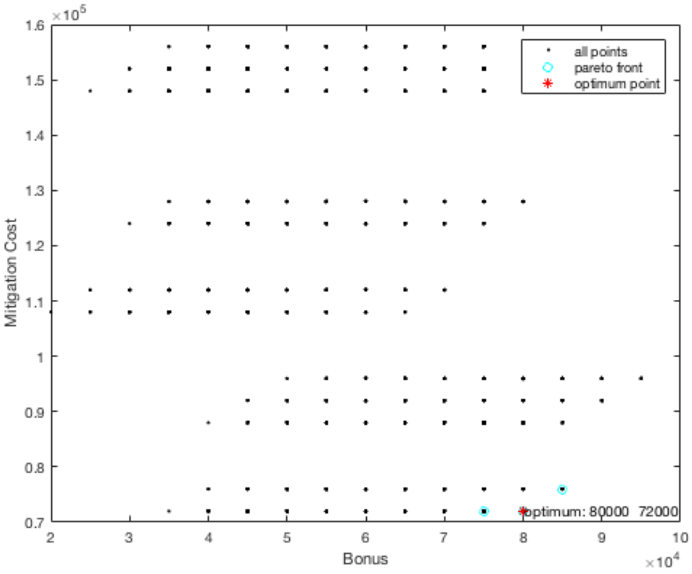


Figure 4: Pareto Front – Bonus versus Risk Mitigation Cost

The optimization results showed that it was possible to obtain an overlapping combination that can produce a satisfactory bonus-risk mitigation cost trade-off. In this case, 3 points highlighted in the plot can offer a potential beneficial trade-off. The first point could offer a combination of $ 75,000 for the bonus and $ 72,000 for the mitigation cost. The third point could offer a combination of $85,000 for the bonus and $ 76,000 for the mitigation cost. However, the optimum overlapping combination was the point in the middle. This point is represented by point 19 in Table 4. The overlapping combination for this point was [0, 0, 25, 75, 25, 50, 75, 75, 50, 75, 0, 0], the risk mitigation cost was $ 72,000, and bonus was $ 80,000. This overlapping combination can produce the minimum duration of 19 days without risk occurrence and 37 days with risk occurrence. The optimum solution is not the one with maximum overlapping in all activities.

4.1 Implications of the results

The implication of the results shall be interpreted according to the organization or to the decision-maker's risk tolerance and available resources. However, the result showed that the planned risk responses applied were not sufficient to promote a significant change in the duration of the project. The mean duration decreased by only 10%. The chance of finishing the project in less than 35 days increased by only 24%. These results show that the fast-track strategy for the project continued to be compromised, suggesting the need for additional risk response actions.

Another aspect to be noticed is that applying the optimum overlapping combination without risk mitigation actions could compromise the goal of finishing the project earlier. In this case, if risks occur, the duration will be longer than the original duration (35 days). However, the results showed that it might be worthy to the project to expend financial resources and try to mitigate the risks that can compromise the fast-track strategy of the project. This can be seen by the points in the Pareto Front where the mitigation cost was less than the bonus that can be awarded and the optimum Pareto point can produce a positive balance of $ 8,000. On the other side, seeking to maximize the positive balance without applying any mitigation action had a chance to produce a negative balance, considering the occurrence of risks and the cost caused by extra duration.

The analysis of the results should take into account the original total duration of 35 days, as the objective of the fast-tracking strategy is to compress the schedule duration. Then, in this case, if risks occur, attaining the final duration in less than 35 days can be threatened for all points in the Pareto Front. Additionally, results show that different overlapping combinations can produce the same project duration. In this case, the decision cannot only rely on project duration and another criterion should be used.

5 CONCLUSIONS

The objective of this study was to develop a conceptual evaluation of risk mitigation responses in fast-track construction projects. The specific goals of this study were to (1) quantify the ability of the risk responses/strategies to mitigate the risks and the overall impact on the project target performance metrics, and (2) determine the impact boundaries of the risks and the optimal combination of the risk responses or strategies to produce minimum risk mitigation cost and maximum contract bonus.

The results of the conceptual case study showed that the risk response actions helped in decreasing the project risk exposure. After the application of the risk responses, lower values for the main statistical measures of maximum duration, mean, standard deviation, variance, and median were obtained compared to results without the risk responses. However, the most probable duration remained the same. Therefore, the project risk exposure was decreased, but the fast-track strategy continued to be threatened. On the other side, it is possible to obtain an overlapping combination that can produce a satisfactory bonus-risk mitigation cost trade-off and a positive balance of $ 8,000. In this case, decision-makers can accept the risk knowing the potential impact of the risks and risk responses, or they can change the project strategy, or they can try to apply additional responses to mitigate the risks. But, adopting the optimum overlapping without considering the application of proactive actions to mitigate the possible risks can compromise the fast-track strategy. Also, considering the occurrence of risks, maximum overlapping level on all activities does not guarantee the optimum trade-off between bonus and mitigation cost.

The importance of these results is that a quantitative evaluation of the application of risk mitigation responses can give objective information to the decision-makers about project risk exposure. In this way, they can evaluate beforehand the potential reduction in the project risk exposure that can be obtained by the planned responses. They can also obtain the overlapping combination that can produce an optimum positive balance between risk mitigation cost and potential bonus. The evaluation can be done before actually making the investment. However, decision-makers and companies should evaluate the results according to their risk tolerance, their capacity to proactively respond to risks, and the scenario of the project to make the decision about what schedule strategy to adopt.

Although this study sheds some light on the evaluation of risk mitigation responses on fast-track construction projects, there are limitations to be considered. The model developed made use of simplifications and synthetic data to demonstrate the concept to be further developed. Ongoing studies in this area will make use of a more robust simulation model and use real data collected from the industry.

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References

Abuwarda, Z. and Hegazy, T. 2016. Flexible Activity Relations to Support Optimum Schedule Acceleration. *Journal of Construction Engineering and Management,* **142**(11): 06016004. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001193.

Bogus, S., J. Diekmann, Molenaar, K., Harper, C., Patil, S. and Lee, J. 2011. Simulation of Overlapping Design Activities in Concurrent Engineering. *Journal of Construction Engineering and Management,* **137**(11): 950–57. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000363.

Hwang, B., Shan, M., Phua, H. and Chi, S. 2017. An Exploratory Analysis of Risks in Green Residential Building Construction Projects: The Case of Singapore. *Sustainability,* **9**(7): 1116. https://doi.org/10.3390/su9071116.

Cho, K., Hyun, C., Koo, K. and Hong, T. 2009. Partnering Process Model for Public-Sector Fast-Track Design-Build Projects in Korea. *Journal of Management in Engineering,* **26**(1): 19–29. https://doi.org/10.1061/(ASCE)0742-597X(2010)26:1(19).

Cho, K. and Hastak, M. 2013. Time and Cost-Optimized Decision Support Model for Fast-Track Projects. *Journal of Construction Engineering & Management,* **139**(1): 90–101. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000570.

Dehghan, R., Hazini, K. and Ruwanpura, J. 2015. Optimization of Overlapping Activities in the Design Phase of Construction Projects. *Automation in Construction,* **59**(November): 81–95. https://doi.org/10.1016/j.autcon.2015.08.004.

Deshpande, A.S., Salem, O.M. and Miller, R.A. 2012. Analysis of the Higher-Order Partial Correlation between CII Best Practices and Performance of the Design Phase in Fast-Track Industrial Projects. *Journal of Construction Engineering & Management,* **138**(6): 716–24. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000487.

Fan, Z., Li, Y. and Zhang, Y. 2015. Generating Project Risk Response Strategies Based on CBR: A Case Study. *Expert Systems with Applications,* **42**(6): 2870–83. https://doi.org/10.1016/j.eswa.2014.11.034.

Garrido Martins, C., Vanessa, V. and Bogus, S.M. 2017. Risk Assessment in Fast-Track Construction Projects: A Conceptual Model. *CSCE/CRC Construction Specialty Conference*, Vancouver, BC, Canada.

Gerk, J.E.V., and Qassim, R.Y. 2008. Project Acceleration via Activity Crashing, Overlapping, and Substitution. *IEEE Transactions on Engineering Management,* **55**(4): 590–601. https://doi.org/10.1109/TEM.2008.927786.

Gündüz, M., Nielsen, Y. and Özdemir, M. 2013. Quantification of Delay Factors Using the Relative Importance Index Method for Construction Projects in Turkey. *Journal of Management in Engineering,* **29**(2): 133–39. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000129.

Gwak, H., Son, S., Park, Y. and Lee, D. 2016. Exact Time–Cost Tradeoff Analysis in Concurrency-Based Scheduling. *Journal of Construction Engineering and Management,* **142**(10): 04016054. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001164.

Hallowell, M.R. and Gambatese, J.A. 2009. Construction Safety Risk Mitigation. *Journal of Construction Engineering and Management,* **135**(12): 1316–23. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000107.

Hazini, K., Dehghan, R. and Ruwanpura, J. 2014. An Evolutionary Optimization Method to Determine Optimum Degree of Activity Accelerating and Overlapping in Schedule Compression. *Canadian Journal of Civil Engineering,* **41**(4): 333–42. https://doi.org/10.1139/cjce-2013-0194.

Mbachu, J. and Taylor, S. 2014. Contractual Risks in the New Zealand Construction Industry: Analysis and Mitigation Measures. *International Journal of Construction Supply Chain Management,* **4**(2): 22-33. https://doi.org/10.14424/ijcscm402014-22-33.

Moazzami, M., Dehghan, R. and Ruwanpura, J.Y. 2011. Contractual Risks in Fast-Track Projects. *Procedia Engineering*, The Proceedings of the Twelfth East Asia-Pacific Conference on Structural Engineering and Construction EASEC12, 14: 2552–57. https://doi.org/10.1016/j.proeng.2011.07.321.

Newitt, J.S. 2009. *Construction Scheduling: Principles and Practices*. 2nd ed. Upper Saddle River, N.J: Prentice Hall.

Peña-Mora, F. and Li, M. 2001. Dynamic Planning and Control Methodology for Design/Build Fast-Track Construction Projects. *Journal of Construction Engineering and Management,* **127**(1): 1–17. https://doi.org/10.1061/(ASCE)0733-9364(2001)127:1(1).

Project Management Institute, ed. 2013. *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*. 5th edition. Newtown Square, Pennsylvania: Project Management Institute, Inc.

Qazi, A., Quigley, J., Dickson, A. and Kirytopoulos, K. 2016. Project Complexity and Risk Management (ProCRiM): Towards Modelling Project Complexity Driven Risk Paths in Construction Projects. *International Journal of Project Management,* **34**(7): 1183–98. https://doi.org/10.1016/j.ijproman.2016.05.008.

Zhang, Y. and Fan, Z. 2014. An Optimization Method for Selecting Project Risk Response Strategies. *International Journal of Project Management,* **32**(3): 412–22. https://doi.org/10.1016/j.ijproman.2013.06.006.