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RISK ASSESSMENT IN FAST-TRACK CONSTRUCTION PROJECTS: A CONCEPTUAL MODEL

Garrido Martins, Claudia[1,2], Valentin, Vanessa[1] and Bogus, Susan M.[1]
[1] University of New Mexico, Department of Civil Engineering, Albuquerque, NM, US
[2] cgarrido@unm.edu

Abstract: Construction projects play a major role in the economy of a country and they are also recognized as the most exposed to risks and uncertainty. Despite the complexity of engineering problems in a construction project, a constant pressure is placed on managing the duration of the projects while meeting regulatory obligations, emergency/disaster recovery, and time-to-market limitations. Hence, traditional construction schedules can be compressed through schedule crashing or activity overlapping. Projects that apply activity overlapping are called fast-track projects. However, risks resulting from activity overlapping can affect the project duration and compromise the fast-track strategy. In this study, we analyze the overall duration of a fast-track construction project subjected to various risks arising from different levels of overlapping. A conceptual model was developed using a Monte Carlo simulation to apply different levels of overlapping for each activity in a simple construction schedule. The simulation includes risk factors defined as their occurrence probability and schedule impact for each level of overlapping. The output of the model includes: 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. Additionally, an optimization problem is formulated to find the optimal level of overlapping for each activity. The results can assist decision-makers with information to understand how overlapping levels and project risks affect the expected project duration and what risks must be mitigated to avoid the threat of delays to the project duration.

1. INTRODUCTION

Construction projects play a major role in the world economy. In the US, the construction industry represents around 4% of the Gross Domestic Product (GDP) (U.S. Department of Commerce 2016). In Canada, the construction industry represents around 7% of the GDP (Government of Canada 2017). In the European Union, represented by 28 countries (EU-28), according to the statistical office of the European Union (Eurostat), the construction sector represents more than 5% of the gross value added, and it continues to be a high importance sector even though its relative share in EU's economic activity had declined over recent years (Eurostat 2016). Despite the complexity of engineering problems in a construction project, a constant pressure is placed on managing the duration of the projects while meeting regulatory obligations, emergency/disaster recovery, and time-to-market limitations. Under this scenario, the traditional construction schedules can be compressed by the application of some techniques, such as activity crashing, activity overlapping, and activity substitution. Projects that apply activity overlapping technique in their schedules are called fast-track projects.

Although construction projects are inherently risky, from a risk management point of view, when project activities are overlapped, new risks could arise, or the characteristics (probability and impact) of current risks could change. As result, planned project duration could be affected compromising the fast-tracking strategy. Hence, the relation between activity overlapping and risk must be understood in order to provide tools for better management of fast-track project schedules, avoiding the threat of delays to the project duration.

2. BACKGROUND AND PROBLEM STATEMENT

Although fast-tracking has been investigated since 1983, when Baker and Boyd (1983) studied fast-tracking for nuclear power plant construction, there are important issues yet to be explored. There is no extensive literature about faster fast-track (flash-track) projects, and no focus in the investigation of project risks when the activities are highly overlapped. 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 tradeoff, 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. Cho et al. (2009) developed a fast-track partnering process model that combined the fast-track approach with the partnering concept. Moazzami et al. (2011) investigated the contractual risks associated with disputes, claims, and legal issues in fast-track projects. Deshpande et al. (2012) investigated a correlation between Construction Industry Institute (CII) best practices and the performance of the design phase in a fast tracking project. Austin et al. (2016) identified 18 essential industry practices for the successful delivery of a faster fast tracking project. Alhomadi et al. (2011) investigated the relationship of fast-track and predictability to attain the planned project objectives of cost, time, and quality.

Recent studies have focused on optimization of project duration, time-cost tradeoff, and the impact of rework on fast-track projects. Gerk and Qassim (2008) tried to find an optimal mix between the application of crashing, overlapping and substitution techniques to accelerate a project and the minimum resulting cost. Dehghan et al. (2010) developed a framework for optimizing activity overlapping in construction projects and tried to answer how much overlapping is desirable or which degree of overlapping is optimum based on a loss-benefit tradeoff to obtain the maximum net benefit. Bogus et al. (2011) investigated the project overall duration optimization using simulation and found that overdesign is the better strategy of overlapping when considering just duration, and also the optimal overlapping amount considering the characteristics of evolution and sensitivity in a pair of activities. Cho and Hastak (2013) proposed a time and cost optimization model for making the decision of fast-tracking. Finally, a series of studies tried to develop an optimization method for a fast-track application to obtain a better time-cost tradeoff (Roemer and Ahmadi 2004; Gerk and Qassim 2008; Dehghan et al. 2011; Cho and Hastak 2013; Hazini et al. 2014; Dehghan et al. 2015; Abuwarda and Hegazy 2016; Gwak et al. 2016).

On the other hand, there seems to be a consensus in the literature that it is not possible to implement a fast-track approach without facing additional risks. Williams (1995) stated that if the management team does not want to operate in the traditional way, the project team must embrace the risks and plan for them, where a detailed plan is essential on a fast-track project. Krishnan et al. (1997) pointed out that when overlapping, there is a possibility of an increased duration and effort of the successor activity, or a loss of flexibility in the predecessor activity interpreted as a quality loss. According to Bogus (2004), there is a risk to speed up the project delivery process. Moazzami et al. (2011) stated that fast-tracking results in additional risks and uncertainties and Dehghan and Ruwanpura (2014) asserted that overlapping is essentially risky, and consequences can be both rework and more changes in the project.

In this way, some authors pointed out some risks that can arise in a fast-track project. Williams (1995) observed that a fast-track project has little time for design optimization, causing overdesign in some parts of the project; the risk of rework, when the system is undersized or unable to operate as designed, and the risk of some material wastage, in order to optimize the usage of labor, which costs are higher than material. Fazio et al. (1988) highlighted some problems such as design errors, omissions, and changes, lack of coordination, and risks of loss of financial benefit caused by cost of changes and claims, loss of time savings caused by delays, decreasing of the project cost control caused by lack of design optimization, and insufficient procurement specifications. Bogus (2004) identified the risks of rework and consequent additional costs and resources, increase in change orders, lack of design optimization and consequent increase in material costs and rework. Moazzami et al. (2011) cited that the most important contractual risks in a fast-track project are: (1) cost overrun and inaccurate cost estimating, (2) design errors and omissions, (3) delay damages, (4) numerous change orders, (5) construction rework and modifications, and (6) overlooked work (assigned to no party). In general, rework is the most cited risk by prior studies.

Though past research explored some aspects of fast-tracking, or overlapping, and also generally recognized that a fast-track approach can impose additional risks, there is a gap related to the assessment of risks in a fast-track project. Considering that risks resulting from activity overlapping can affect the project duration and compromise the fast-track strategy, the objective of this work is to analyze the overall duration of a fast-track construction project subjected to various risks arising from different levels of overlapping. The specific objective of this work is to answer the following questions: (1) What is the probability of attaining the desired fast-track project duration under different risk scenarios and the most probable duration of the project? (2) What is the optimal level of overlapping to obtain the minimum duration? (3) What are the most significant risks and the activities most affected by the risks? In order to attain the aforementioned objective, a conceptual model was developed using a Monte Carlo simulation and optimization formulation to apply different levels of overlapping for each activity in a sample schedule, and the consequent occurrence of risks and their impacts on the duration of a construction project.

3. METHODOLOGY

The proposed framework for the conceptual model is showed in Figure 1. The model was developed considering three main components: the project schedule, a risk parameters table, and the risk occurrence table.

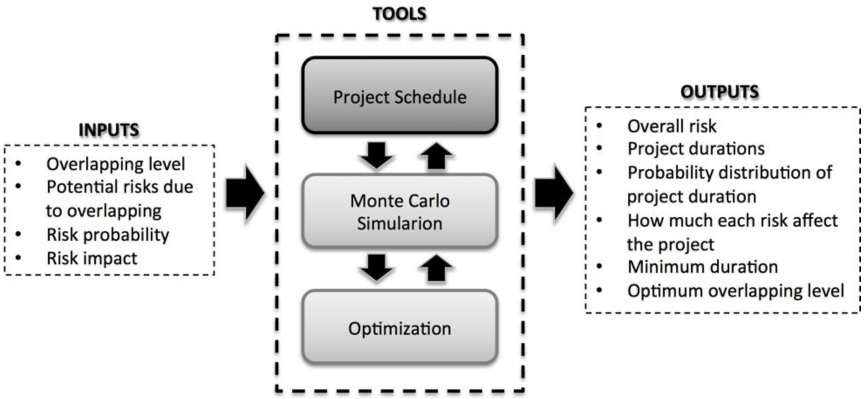


Figure 1: Conceptual model framework

3.1 Inputs

Each component in the conceptual model has variables that must be considered during the formulation of the model. The development of the schedule considered the following variables: activity duration, overlapping level (lag), activity early start, and activity early finish. The formulation of the model uses the following indexes for variables: where i is an activity, and p is its predecessor activity.

The activity duration d_i (Eq. 1) is the original time to complete the activity, without the impact of any overlapping risk. The duration is expressed in days.

[1] d_i ∀ i = 1,…,N

The overlapping level OL_ip (Eq. 2) refers to the amount of time that a successor activity will start before the predecessor activity finishes, considering a traditional schedule relationship of finish-to-start. Three overlapping levels were considered in this model: low, medium, and high (Figure 2). A percentage value, representing the amount of overlapping to be applied, was associated with each overlapping level. These percentage values were defined according to the overlapping framework proposed by Peña-Mora and Li (2001) in which it was assumed that activities could be divided in increments of 25% of work completion and consequently allow overlapping at different intervals. During the simulation, an overlapping level for each activity link was randomly chosen following a discrete uniform distribution with the three possible values of overlapping level.

[2] $OL\_ip \in \{0.25, 0.50, 0.75\} \quad \forall\ i = 1,\ldots,N;\ p = 1,\ldots,N;\ p = i - 1$

The amount of overlapping O_ip (Eq. 3) between predecessor and successor activities is related to the duration of the predecessor activity, therefore the amount of overlapping can be calculated as:

[3] $O\_ip = d\_p \cdot OL\_ip \quad \forall\ i = 1,\ldots,N;\ p = 1,\ldots,N;\ p = i - 1$

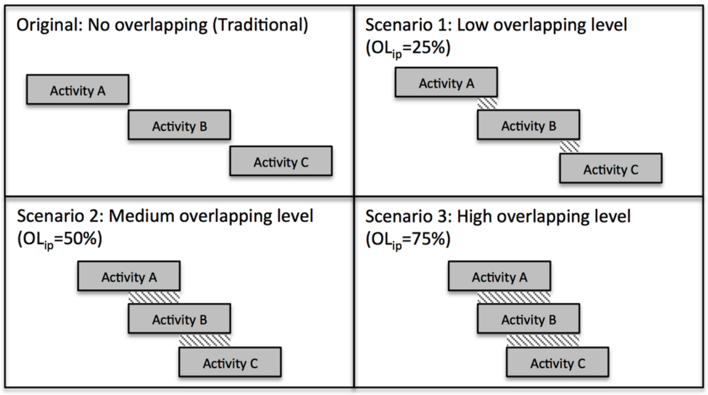


Figure 2: Overlapping levels

Activity early start (ES_i) is the moment in time when the activity is expected to start. Following the Critical Path Method (CPM) network logic, the start of an activity depends on the type of the activity relationship applied. For the purpose of this research, a constraint is applied to ES_i, where the successor activity cannot finish before predecessor activity; it can only finish later or at the same time. This way, ES_i (Eq. 5) will be equal to the early finish of predecessor activity (EF_p), minus the amount of overlapping O_ip, plus the activity duration (d_i) if this value is equal or greater than the early finish value of the predecessor activity. Otherwise, ES_i will be equal to the early finish of predecessor activity (EF_p) minus the activity duration (d_i) and both activities would finish at the same time. The final ES_i value is round up to avoid values that represent partial days.

[4] $ES\_i \quad \forall\ i = 1,\ldots,N$

[5] $$ES\_i = \text{Round up} \begin{cases} EF\_p - O\_ip + di, & EF\_p - O\_ip + d\_i \geq EF\_p \\ EF\_p - d\_i & \text{, otherwise} \end{cases} \quad \forall\ i = 1,\ldots,N;\ p = 1,\ldots,N;\ p = i - 1$$

Activity early finish (EF_i) is the moment in time when the activity is expected to end. Hence, EF_i (Eq. 6) is originally defined as the sum of activity early start (ES_i) and duration (d_i). EF_i must be equal or greater than the early finish of the predecessor activity (EF_p).

[6] $EF\_i = ES\_i + d\_i \quad \forall\ i = 1,\ldots,N$

[7] $EF\_i \geq EF\_p \quad \forall\ i = 1,\ldots,N;\ p = 1,\ldots,N;\ p = i - 1$

Moreover, the risk parameters table contains the potential risks that can affect the construction project due to overlapping. Although this study used hypothetical risks, it is possible to mention some examples of risks that can arise due to overlapping, for instance, construction site space constraint, rework on successor activity due to errors on predecessor activity, equipment allocation problem, shortage of equipment, and accidents to name a few (Gündüz et al. 2013).

In this study, each hypothetical risk arising from overlapping is defined through the identification of two main variables: risk probability of occurrence and risk impact. In this study, it is assumed that risk factors arising from overlapping are defined by their occurrence probability and their potential impact on the schedule. These risk factors can vary for each level of overlapping, hence a value of probability and a value of impact were defined for each level of overlapping.

Risk occurrence probability (P_i) refers to the likelihood of a risk event occurring and is expressed as:

[8] 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

Risk impact (I_i) refers to the impact on the schedule (in terms of days) caused by the risk occurrence. In this study, a PERT distribution was used to calculate the risk impact (Eq. 10).

[9] 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

[10] 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

Finally, the risk occurrence table links the risk parameters table with the schedule and contains the logic that simulates the risk occurrence and the amount of impact that will be transferred to the duration of the activity impacted by the specific risk. The risk frequency (F_i) defines the occurrence or nonoccurrence of the risk and is defined by a binomial distribution as:

[11] F_i ∈ {0,1} ∀ i = 1,…,N

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

The total risk impact (RI) is the sum of the impact of all risks that occurred for a specific activity. The impact affects the duration of an activity and is defined as:

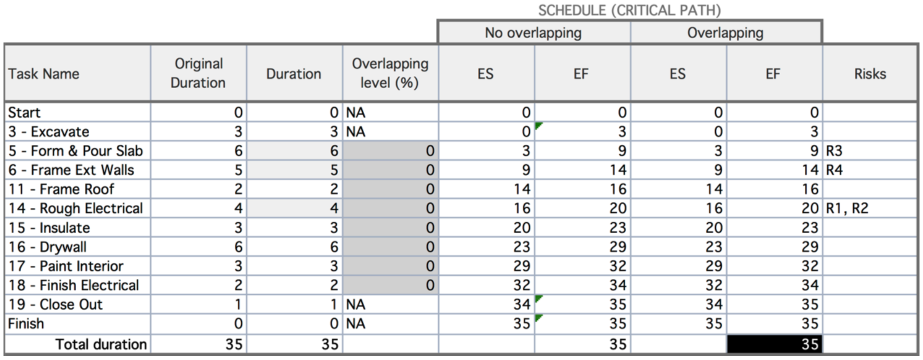
[13] RI = ∑ (F_i · I_i) ∀ i = 1,…,N

Now, the activity early finish (EF_i) can be redefined to represent the effect of the total risk impact (RI) on the activity duration. Then, EF_i (Eq. 14) will be equal to activity early start (ES_i), plus duration (d_i), plus total risk impact (RI).

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

3.2 Project Data and Tools

The sample schedule was an example provided by Newitt (2009) with an original duration without overlapping of 35 days. The sample schedule was reproduced in *Microsoft Excel* with the logic of activity relationships and overlapping (Figure 3). For the purpose of demonstrating the methodology, only the critical path containing 10 activities was used during the simulation. The assumption of this model was that all activities could be overlapped, except the first and the last activity. This way, overlapping was defined to occur in 8 activities. Additionally, each risk was associated to only one activity. In this example project, three activities could be impacted by a hypothetical risk and rough electrical activity had two risks associated. Table 1 contains the risk parameters, probability and impact, used in this simulation. The values are synthetic data created for the purpose of demonstrating the methodology. Future research will focus on how to specifically quantify these values.



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 3: The model sample schedule

Table 1: Risk parameters

	Probability per Overlapping Level			Impact per Overlapping Level (PERT)* (days)								
				Low			Medium			High		
	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
R2	0.1	0.1	0.2	5	8	15	5	8	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

Two tools from *Palisade DecisionTools Suite 7.0.0* were used to run the simulations and produce the results. *@RISK* was used to run the Monte Carlo simulation to produce 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. The optimization process to obtain the optimal level of overlapping for each activity with the minimum project duration used the *RISKOptimizer* tool. During the optimization process, a number of trials 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.

3.3 Simulation Runs

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% with 95% confidence level. In this case, 5,100 iterations were necessary to attain the convergence of the output. The optimization model was setup to run 10,000 trials and using Latin Hypercube sampling. The simulation was automatically stopped at 6,562 trials because the best solution was found.

3.4 Outputs

The outputs were extracted from the simulation results and comprise the information to the decision-making process. The project schedule duration (SD) can be formulated as:

[15] $SD = ES_1 + \sum(d_i + RI) - \sum[(d_p + RI) \cdot OL_{ip}] \quad \forall\ i = 1,\ldots,N;\ p = 1,\ldots,N;\ p = i - 1$

Considering the objective to find the optimum combination of activity overlapping, while minimizing the project schedule duration and the risk, the optimization model can be represented as:

[16] $\min SD = ES_1 + \sum(d_i + RI) - \sum[(d_p + RI) \cdot OL_{ip}]$

subject to $\sum RI > 0$

$OL\_ip > 0 \quad \forall\ i = 1,\ldots,N;\ p = 1,\ldots,N;\ p = i - 1$

4. ANALYSIS

The analysis of the results should take into account the original total duration of the project (35 days) as the objective of the fast-tracking strategy is to compress the schedule duration. The main results of the simulations are shown in the tables and figures below.

4.1 Project Duration

The summary statistics for the project's total duration is shown in Table 2 and its probability distribution is graphically illustrated in Figure 4. According to the results, the probability of attaining a total duration less than 35 days was equal to 21.4%, with the minimum duration of 16 days having a less than 1% chance. The total duration varied from 23 days to 81 days with 90% of probability, and the maximum duration reached 111 days. The mean duration obtained was 47.6 days and the median 44 days. Finally, the mode value obtained, which can be interpreted as the most probable duration of the project, was 38 days. Although according to the results it was possible to attain a total duration less than 35 days, a further analysis of the raw data produced by the simulation showed that a total duration less than 25 days was only possible without the occurrence of any of the risks.

Table 2: Summary Statistics for the Total Duration

Summary Statistics for Total duration	
Statistics	(days)
Minimum	16
Maximum	111
Mean	47.6
Std Dev	17
Variance	291
Median	44
Mode	38

4.2 Impacts of Risks

In this conceptual model, only four risks were considered and identified by the codes R1, R2, R3, and R4. According to the Tornado graph in Figure 5 it is possible to note that R1 was the risk input that most affected the mean duration of the project, with the largest variance. Following R1, the order of the risks that most affected the mean duration was R4, R2, and R3. Consequently, as each risk was only associated with one activity, and the activity rough electrical had two risks associated, the most impacted activities were rough electrical, frame external walls, and form & pour slab.

4.3 Optimum Overlapping Level

The results of the optimum overlapping level considered the outputs of both simulations run using Monte Carlo simulation and the optimization model. The summary of the optimum overlapping levels to attain the minimum total duration according to both simulations is shown in Table 3. Therefore, the minimum duration of 16 days obtained by the Monte Carlo simulation, could be attained if all activities were overlapped to the maximum (75%), except for the activities 14 – Rough Electrical and 17 – Paint Interior with an overlapping level of 50%. However, as explained before, this duration could only be attained without the occurrence of any of the risks. On the other side, the results produced by the optimization model showed that the minimum possible duration, considering the occurrence of the risks, was 37 days. In this case, 12 different overlapping level alternatives could possibly produce this result.

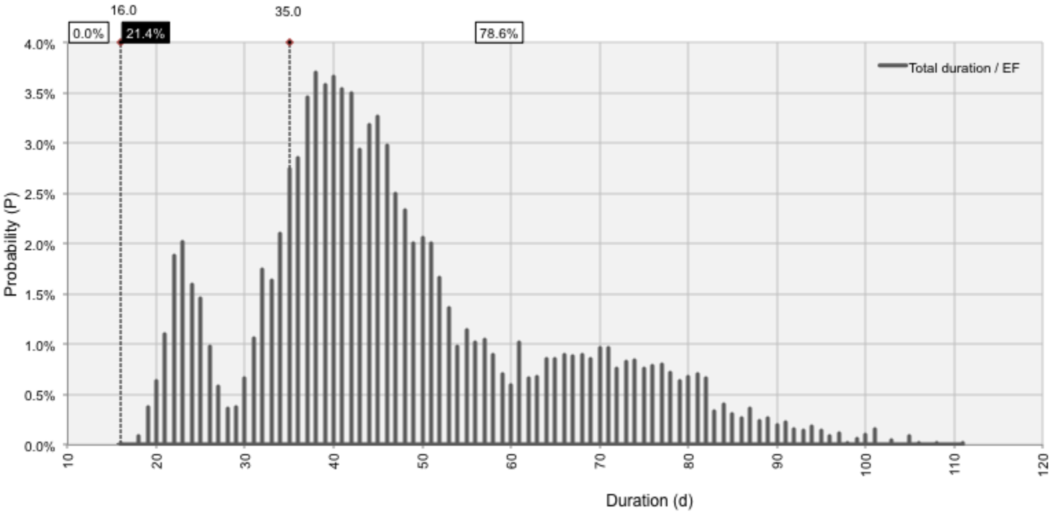


Figure 4: Total Duration (days) Probability Distribution

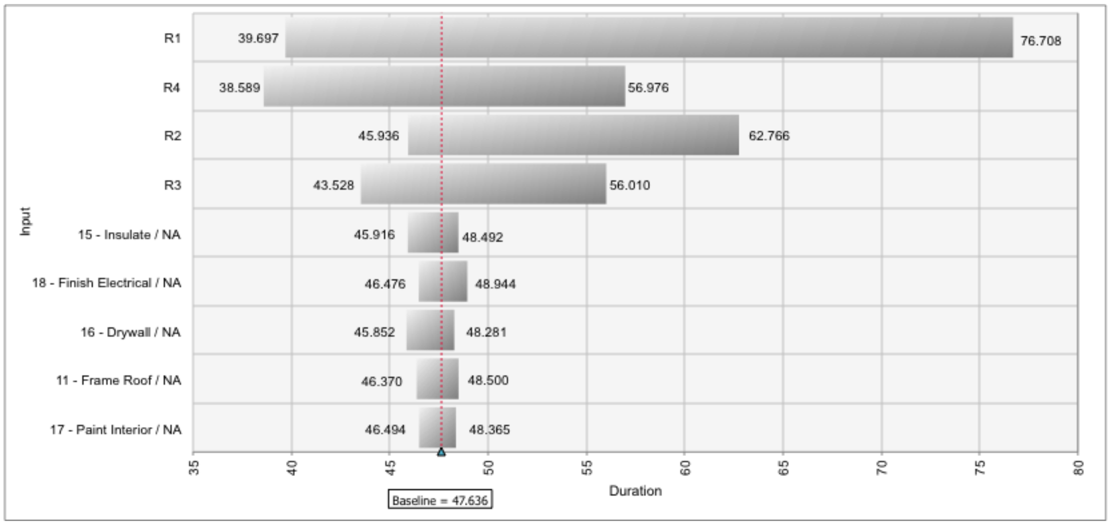


Figure 5: Tornado Graph: Impact of Inputs on Total Duration (days)

Table 3: Optimum Levels of Overlapping

	Optimum Level of Overlapping (%)												
	Without risk (Monte Carlo simulation)	With risk (Optimization model)											
Task		1	2	3	4	5	6	7	8	9	10	11	12
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	75	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	50	50	75	75	50	25	50	25	25	25	75	75
14 – Rough Electrical	50	50	50	75	75	75	75	75	75	50	50	50	50
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	75
17 – Paint Interior	50	75	50	75	50	75	75	50	50	50	75	50	75
18 – Finish Electrical	75	75	75	75	75	75	75	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
minimum duration (days)	**16**	**37**											

4.4 Implication of the results

According to the results for the example project, the chance to attain project duration less than the original duration of 35 days is less than 21.4%, and therefore there is a high chance (78.6%) that the fast-track strategy is compromised. The most probable duration of 38 days is longer than the original duration of the project without overlapping. Additionally, considering the no occurrence of any of the risks, the results show that there is a minimum chance to attain the minimum duration of 16 days with all activities overlapped by 75%, with exception of the activity form & pour slab, rough electrical, and paint interior overlapped by 50%. On the other hand, considering the occurrence of the risks, the minimum duration of the project is 37 days when using 12 different combination of overlapping level alternatives. Besides, the inputs that have the largest impact on the distribution of the duration are exactly the four risks, suggesting that proactive actions against the risks shall be necessary to reduce their impact on output.

Implication of the results shall be interpreted according to the organization or decision-maker's risk tolerance. Risk-seeking organization/decision-maker can accept the high chance of not meeting the original duration and move forward with the fast-track approach without any mitigation response. In the case of a risk-aversion organization/decision-maker, considering that the goal of a fast-track approach is to compress the original schedule and obtain a project duration that is shorter than the original project's duration without overlapping, the results of this hypothetical project show that mitigation actions are necessary to increase the chance of finishing the project before the original 35 days. The decision-making process can be an iterative process where the decision-maker can test alternative mitigation scenarios and ultimately make the decision to not adopt a fast-track approach.

5. Conclusions

The objective of this work was to analyze the overall duration of a fast-track construction project subjected to risks arising from different levels of overlapping and answer the questions: (1) What is the probability of attaining the desired fast-track project duration under different risk scenarios and the most probable duration of the project? (2) What is the optimal level of overlapping to obtain the minimum duration? (3) What are the most significant risks and the activities most affected by the risks?

In this example project, the results show that the fast-track strategy can be threatened without a proactive action to mitigate or eliminate the risks, and therefore risks arising from overlapping should be analyzed in any overlapping strategy. The chance of not attaining project duration less than the original duration is higher (78.6%) than the chance of attaining a duration less than 35 days (21.4%) and a most probable duration of 39 days. The minimum duration of 37 days, considering the possibility of risk occurrence, can be obtained through 12 different combination of overlapping level alternatives. Finally, the four hypothetical risks in the project example are the inputs that cause largest impact on the duration mean. Decision-makers should evaluate the results according to their risk tolerance, their capacity to proactively response to the risks, and the scenario of the project to make the decision about what schedule strategy to choose.

Although this study can give some answers about how to quantify the impact of the risks on the project duration arising when considering different levels of activity overlapping, there were some limitations that need to be further explored. This conceptual model considered that the traditional activity sequencing with no overlapping has no risk associated, which is not realistic. Also, in order to simplify the model, only the activities on the critical path were considered, because the critical path is the longest path of a project schedule but the critical path might change when overlapping activities. For a more robust model, all activities should be considered, starting the overlapping process by the activities on the critical path. Furthermore, this model considered hypothetical risks and risk parameters values, such as probability and impact. Future studies focus in addressing these limitations, obtain real data from the industry, and include other aspects, such as the impact on profit.

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