Applying Scenario-Based Planning in Construction Projects Using Simulation Modeling

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1.1 Introduction

Project planning, one of the most crucial steps in construction operations, defines the objective of the project, sets the goals, and determines how they will be achieved. During the planning phase, specific activities should be defined, the schedule created, and the cost calculated. According to the Project Management Institute [6], the discipline of project management can be defined as “the art of directing and coordinating human and material resources throughout the life of a project by using modern management techniques to achieve predetermined objectives of scope, cost, time, quality, and participation satisfaction.”

Currently, most project planning initiatives involve a number of teams, each consisting of engineers, superintendents, estimators, coordinators, and managers working collaboratively to devise the project plan. For example, work packages must be completed, resources located, and construction methods and project costs determined.

Daum (2001) [2] defines scenario planning as “the process in which managers invent and then consider, in depth, several varied scenarios of equally plausible futures with the objective to bring forward surprises and unexpected leaps of understanding.” Simpson (1992) [4] presented scenario planning as “the process of constructing alternate futures of a business’ external environment. The goal is to learn to use these alternative futures to test the resiliency of today’s action plan.”

Scenario planning was originally created based on the predict-and-control approach, replacing the forecast component with a probabilistic assessment that helped in predicting the most likely future. This advancement didn’t provide a fundamental change from other forecast approaches [5].

To operate in an uncertain world, managers need to be able to question their assumptions about the way the world works in order to see the world more clearly. The purpose of scenario planning, therefore, is to help managers to change their view of reality in order to match it up more closely with reality as it is and reality as it is going to be. The end result, however, is not an accurate picture of tomorrow, but better present decisions about the future [2].

Scenario planning is an attempt to describe what is possible rather than forecasting the future. The outcome of each scenario is a different future, all of which are plausible. The challenge is in determining how we can prepare for each future.

Scenario planning usually takes place in a workshop setting with different levels of experts; the point of this structure is to have a wide range of ideas from which the group can produce more scenarios than those usually considered. The process should include the personnel that will be involved in applying the strategy based on the scenario analysis. Without their input, the scenario planning is significantly limited.
may lack consideration of a number of important issues that should be included in the strategy [3].

Scenario planning has number of benefits: it helps managers expose the blind spots in project plans and forces them to look outside the box; also, it is easier to define scenarios in the early stages of the project. The method helps managers to identify and realize the reasons for disagreements during the evaluation of different scenarios [3].

In construction, scenario planning is used to define the best course of action for constructing a project. It helps planners to fully understand the project and prepare for any unforeseen issues that may arise during construction.

In the city of Edmonton, with the help of the construction engineering group at the University of Alberta, simulation has been used for years to plan a number of projects, specifically in relation to tunnelling. The Simphony framework is used to simulate most of the tunnelling projects undertaken by the City of Edmonton. With any simulation modelling, the process must be studied closely to devise the best possible representation. In tunnelling construction simulation, a number of visits to the project site must be conducted to record the activities involved, and to note the durations and required resources. These resources include workers and materials or equipment. Equipment, for example, is susceptible to breakdowns, so possible breakdowns should be modelled. As well, material delivery delays could become crucial in determining a project’s duration, so the simulation model should include a supply-chain component.

The City of Edmonton uses simulation as a planning tool during the pre-construction planning phase. In this phase, a number of alternatives are proposed for a specific project. Then, a simulation model is created for each alternative, and a comparison helps to determine the best choice. During construction, simulation can also help to predict the completion date as well as the expected cost of the project.

Simphony is a simulation environment developed by the construction engineering research group at the University of Alberta to model construction operations. It supports the development of special purpose simulation (SPS) as well as general purpose simulation (GPS) [1].

The Simphony environment provides a number of services such as: Simulation, where Simphony supports discrete event simulation including event scheduling as well as contentious simulation; Statistical, which supports the collection of standard statistic averages, standard deviation, minimum and maximum, and also supports graphical representation of the statistics collected via cumulative density function (CDF), histogram, and time graph; Tracing, which allows the user to trace the results and also helps the developer and the user to debug the simulation model; and Animation. Figure 1 shows the Simphony interface.
1.2 Project Information

The case study involves constructing multiple tunnels under the umbrella of the Mill Woods Double Barrel (MWDB) project for flood reduction in the neighbourhood of Mill Woods.

The objective of the MWDB project is to upgrade drainage facilities that will result in reduced risk of flooding in Mill Woods priority neighbourhoods. “Reduced risk of flooding” refers to approximately 80% to 90% less flooding being experienced in the future based on the reference storm event of July 2004. In the study area, a major storm-water bottleneck exists at 30 Avenue and 91 Street (one 1950 mm and two 2775 mm diameter double barrel pipes discharge into one 2775 mm diameter double barrel on 30 Avenue). The objective is to increase storm water outlet capacity; the recommended concept design was to replace the DB with a new tunnel to increase the level of service to Mill Woods and to convert the existing DB into sanitary use as an outlet for the SESS area.

Major project components include the installation of new storm trunks, conversion of double barrel to sanitary trunk, and 10 connections and tie-ins. A concept review was conducted and recommendations presented including the following:

- Design and develop costs for the concept to convert the Mill Woods Double Barrel to a sanitary outlet for SESS.
  - Install 3500 mm diameter storm sewer along 30 Avenue from 91 Street to Calgary Trail (length = 1.85 km; refer to Figure 2).
  - Install 2920 mm diameter storm sewer from 91 Street and 30 Avenue to Knottwood Road and 85 Street (length = 1.7 km).
  - Design the necessary re-connections to the new storm trunks and to convert the existing DB to full sanitary tunnel.
- Additional local flood relief measures within priority Mill Woods neighbourhoods will be required (not in current scope of the project).
Figure 2 shows the project and tunnels location.

1.3 MWDB scenario analysis

During the preconstruction analysis, the project team met and proposed two possible scenarios. For each scenario, the project team further proposed sub-scenarios, as follow:

- Running two ways tunnelling using a 10 m diameter working shaft, the two tunnels on an angle which required more space to accommodate trains (two for each side) and simplify assembling TBM (see Figure 3)
  - Assume the material loading time is 7 min and unloading dirt is 10 min per car.
  - Eliminate the loading and the unloading time, to reduce cycle time for trains which will affect productivity.
- Running two separate tunnels (see Figure 4)
  - Assume the loading time and unloading time for the 3.5 m diameter tunnel are 7 min and 10 min respectively, and 5 min for the 2.9 m diameter tunnel. In this case, the tunnels will have different working shafts: 37 m deep for the 3.5 m tunnel and 20 m deep for the 2.9 m tunnel, which will consequently affect crane time.
  - Eliminate the loading and the unloading time for both tunnels, by eliminating loading and unloading time. Crane operation is not the controlling process in the tunnel excavation.
  - Use one crane for both tunnels.

A simulation model was built for each scenario using simulation templates, see figure 3 for simulation model snap shots, the simulation models were developed in real time during the workshop. The input data used in the simulation models to calculate the productivity and the duration for scenario 1 and scenario 2 are based on historical data collected form a number of tunnelling projects done by the City of Edmonton Drainage Services department.
1.3.1 Scenario 1: Running two-way tunnelling using a 10 m diameter working shaft

In this scenario, the project team proposed two-way tunnelling using a 10 m diameter, 37 m deep working shaft for both sides, as shown in Figure 4. The major project components are:

- 10 m diameter working shaft 37 m deep
- 6 m diameter removal shaft 37 m deep for the 3.5 m tunnel
- 4.5 m diameter removal shaft 20 m deep
- 3.5 m diameter straight tunnel start up of 100 m
- 3.5 m diameter straight tunnel of 1680 m
- 2.9 m diameter straight tunnel start up of 100 m
- 2.9 m diameter straight tunnel of 1080 m
- 2.9 m diameter curved tunnel of 600 m

Two new scenarios were presented based on material handling at the working shaft.
1.3.2 Scenario 2: Running two separate tunnels

In this scenario, the project team proposed two separate tunnels, one for each side, as shown in Figure 5. The major project components are:

- 6 m diameter working shaft 37 m deep for the 3.5 m tunnel
- 6 m diameter removal shaft 37 m deep for the 3.5 m tunnel
- 4.5 m diameter working shaft 20 m deep for the 2.9 m tunnel
- 4.5 m diameter removal shaft 15 m deep for the 2.9 m tunnel
- 3.5 m diameter straight tunnel start up of 100 m
- 3.5 m diameter straight tunnel of 1680 m
- 2.9 m diameter straight tunnel start up of 100 m
- 2.9 m diameter straight tunnel of 1080 m
- 2.9 m diameter curved tunnel of 600 m

Three new scenarios were presented based on material handling at the working shaft and using one crane for both tunnels.

![Figure 5 Running two separate tunnels](image)

1.4 Results analysis and discussion

Tables 1 to 3 show the total cost, productivity values, and start and finish dates for each scenario based on simulation runs and input data obtained from the City of Edmonton Drainage Services department.

Based on Table 1, scenario 1a has the highest cost among all the scenarios. On the other hand, scenario 2b has the lowest cost; keep in mind that for scenario 1b and scenario 2b, an additional cost must be added to represent material handling systems at the working shaft.

Table 3 shows that production values are highly affected by crane use to handle materials at the working shaft. If we used one working shaft for both tunnels, it has little effect on the 2.9 m diameter tunnel; if we use separate working shafts, it has a large effect at the 3.5 m diameter tunnel. For the last scenario, simulation results show that using one crane for two separate tunnels will improve the production compared to having both tunnels share the same working shaft, as the 2.9 m diameter tunnel has a shallower working shaft than the 3.5 m diameter Tunnel.
For the schedule results, the same should be noticed for both scenarios 1b and 2b. A larger amount of time must be added to compensate for material handling system at the working shaft. Based on the results, the fastest scenario will be 2b and slowest will be 1a.

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1a</td>
<td>$21,416,011</td>
</tr>
<tr>
<td>Scenario 1b</td>
<td>$15,010,979</td>
</tr>
<tr>
<td>Scenario 2a</td>
<td>$15,975,787</td>
</tr>
<tr>
<td>Scenario 2b</td>
<td>$14,036,609</td>
</tr>
<tr>
<td>Scenario 2c</td>
<td>$17,723,204</td>
</tr>
</tbody>
</table>

Table 2 Scenario productivity values

<table>
<thead>
<tr>
<th>Soil Section</th>
<th>Scenario 1a (m/shift)</th>
<th>Scenario 1b (m/shift)</th>
<th>Scenario 2a (m/shift)</th>
<th>Scenario 2b (m/shift)</th>
<th>Scenario 2c (m/shift)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 m diameter straight tunnel</td>
<td>2.15</td>
<td>4.0</td>
<td>2.1</td>
<td>3.9</td>
<td>2.3</td>
</tr>
<tr>
<td>start up of 100 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5 m diameter straight tunnel of 1680 m</td>
<td>4.85</td>
<td>11.4</td>
<td>8.8</td>
<td>13.4</td>
<td>6.0</td>
</tr>
<tr>
<td>2.9 m diameter straight tunnel</td>
<td>2.50</td>
<td>3.75</td>
<td>2.8</td>
<td>3.6</td>
<td>2.5</td>
</tr>
<tr>
<td>start up of 100 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.9 m diameter straight tunnel of 1080 m</td>
<td>5.00</td>
<td>10.6</td>
<td>13.1</td>
<td>13.0</td>
<td>6.5</td>
</tr>
<tr>
<td>2.9 m diameter curved tunnel of 600 m</td>
<td>4.76</td>
<td>12.7</td>
<td>12.2</td>
<td>12.6</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Table 3 Scenarios start date and finish date

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Start Date</th>
<th>Finish Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1a</td>
<td>01/01/2009</td>
<td>27/10/2010</td>
</tr>
<tr>
<td>Scenario 1b</td>
<td>01/01/2009</td>
<td>24/12/2009</td>
</tr>
<tr>
<td>Scenario 2a</td>
<td>01/01/2009</td>
<td>10/02/2010</td>
</tr>
<tr>
<td>Scenario 2b</td>
<td>01/01/2009</td>
<td>11/11/2009</td>
</tr>
<tr>
<td>Scenario 2c</td>
<td>01/01/2009</td>
<td>31/05/2010</td>
</tr>
</tbody>
</table>

From the results above, it will be worthwhile investigating eliminating material handling at working shaft for scenario 1b, and for the 3.5 m diameter tunnel in scenario 2b, since production for the 2.9 m diameter tunnel will not be affected due to its shallow working shaft. Using one crane for both tunnels will not add any benefits since the cost saved by using one crane will be consumed by the increased duration of tunnelling activity.

Other results can be extracted from the model if desired, such as number of shifts required to finish the project, number of working days, and number of off days. Also, a detailed material delivery schedule adds the total dirt excavated from the tunnel.
This analysis was done in real time. The project manager defined these scenarios, and then we developed a simulation model for each scenario. It took us around ten minutes to develop simulation model for each scenario, after which we ran each scenario as a separate run. Each run took around three minutes to finish. After running the models, we collected the results shown previously. The overall duration was about an hour. These results gave the project manager a good idea of how to approach this project.

This case study shows the effectiveness of using scenario based planning for project construction planning utilizing simulation modeling.

1.5 References


