SIMULATION AS A SERVICE IN CONSTRUCTION

Sean Newstead[(a)], Simaan AbouRizk[(b)], Stephen Hague[(c)], Yasser Mohamed[(d)], Junhao Zou[(e)]

[(a)]University of Alberta, 5-080 Markin CNRL Natural Resources Engineering Facility, Edmonton, Alberta, CANADA
[(b)]University of Alberta, 5-080 Markin CNRL Natural Resources Engineering Facility, Edmonton, Alberta, CANADA
[(c)]University of Alberta, 5-048 Markin CNRL Natural Resources Engineering Facility, Edmonton, Alberta, CANADA
[(d)]University of Alberta, 5-048 Markin CNRL Natural Resources Engineering Facility, Edmonton, Alberta, CANADA
[(e)]City of Edmonton, Edmonton, Alberta, CANADA

[(a)]sean@smaconsulting.ca, [(b)]abourizk@ualberta.ca, [(c)]steve.hague@ualberta.ca, [(d)]yaly@ualberta.ca,
[(e)]junhao.zou@edmonton.ca

ABSTRACT

This paper discusses a novel approach used to provide simulation services within the construction industry. In this application, a private company using a simulation system developed at the University of Alberta applied the concept of special purpose simulation modeling to facilitate the use of simulation tools in decision support and construction management. In particular, the special purpose simulation tool was deployed for utility tunnel construction. Background to the state of the art and the construction problem is first provided, followed by discussion of the simulation strategy used (special purpose modeling), then the service provided to clients using the simulation tools, and a more detailed explanation of the input modeling aspects of the problem is given, as they are found to be critical in providing reliable solutions.

Keywords: special purpose simulation, Simphony, modeling, tunnel construction, decision support system, construction management

1. STATE OF THE ART: SIMULATION APPLICATION IN TUNNELING CONSTRUCITON

Computer simulation is sometimes applied in the construction industry to support the decision-making process for different operations. Simulation enables construction practitioners to analyze complex construction processes, evaluate different scenarios, and therefore optimize time and resources for projects. Although simulation has advantages for the construction industry, the challenge is to make simulation accessible to users by presenting it in a simple and more graphical context. In 1973, Halpin introduced CYCLONE which simplified simulation modeling for construction practitioners through the use of graphical representation in modeling (Halpin 1977). CYCLONE models processes based on discrete event simulation. A number of simulation systems have been developed based on CYCLONE, including RESQUE (Chang and Carr 1987) and Stroboscope (Martinez and Ioannou 1994). These are all general purpose simulation (GPS) tools that can model any process, but a user must have an understanding of simulation techniques to use them effectively. This makes it difficult for industry personnel to use these tools.

Over the years, advancements have been made in construction management simulation tools, with applications to tunneling. Researchers introduced special purpose simulation (SPS) to facilitate modeling of specific types of projects, as it can be developed and customized for various users, and has a more user-friendly interface. For example, Simphony (AbouRizk and Hajjar 1998) is a special purpose simulation tool developed specifically for modeling construction processes. Other advancements include 4D modelling methods and Construction Synthetic Environment (COSYE) (AbouRizk and Hague 2009). Additional innovations were presented in Einstein (2004), and Haas and Einstein (2002) (amongst other publications) where an innovative simulation system for tunnel construction simulation named DAT (Decision Aid for Tunneling) is described. Ioannou (1988) also presented a geologic prediction model for tunneling and risk reduction modelling as well as planning and simulation approaches to augment those predictions.

2. SPECIAL PURPOSE SIMULATION MODELING IN SIMPHONY

Simphony is a discrete event simulation system, originally developed by Hajjar and AbouRizk (1999). Simphony supports different modeling constructs to facilitate adoption in various domains; therefore, Simphony at its core was built to facilitate developing modeling templates, which can be developed and customized for various users. The special purpose simulation (SPS) approach enables a practitioner who is knowledgeable in a given domain, but not necessarily in simulation, to easily model a project within that domain using visual modeling tools that have a high degree of resemblance to the actual construction system (AbouRizk and Hajjar, 1998). Examples of special purpose templates (SPS) previously developed and currently supported in Simphony include a tunneling template, a dewatering template, a program evaluation and review technique (PERT) template, an earthmoving template, a structural steel fabrication template, and a range estimating template. We further illustrate the tunneling template in this paper.

3. BACKGROUND TO THE CONSTRUCTION PROBLEM: METHOD

Underground pipe installation typically has two installation methods, trenchless and open cut. The open cut method of installation is suitable (cost effective) to installation depths typically less than 7 meters. Open cut construction requires a large amount of surface area to complete the construction, as a 2:1 slope for a typical open cut angle is typically required. The surface disruption to road traffic and interference with shallow utilities often make trenchless construction more desirable even though it may have a higher unit cost. Trenchless construction is suitable for many depth applications, but is constrained by the type of ground that is present. Trenchless excavation methods vary between hand excavation and machine excavation. For the purpose of this paper, we will focus on the machine excavation application, in particular, the tunnel boring machine (TBM) application, but hand excavation is also used to excavate small sections of the tunnel.

4. TBM CONSTRUCTION

The TBM tunnel construction method, as shown in Figure 1, generally starts by laying out the working shaft location, and thus preparing the working site. The working shaft has a predetermined diameter, and is usually excavated with a backhoe and a drilling rig. The backhoe will excavate the first 2 feet and the drilling rig will excavate the remaining depth. Once at the tunnel alignment depth, the working undercut is constructed, which will start with welding rib 0 to the shaft wall. Rib 0 is the outline of the working undercut and shows the alignment of the tunnel. The working undercut is hand excavated and is generally a larger diameter than the actual tunnel diameter. The working undercut is typically 30 meters in length and is lined with a steel rib and wood lagging to support the ground. The excavation of each meter takes place in 2 stages (benching) whereby the top half is excavated first and supported before the bottom half is completed.

Once the full length of the working undercut is completed, the end of the tunnel (the tunnel face) is supported with wood lagging to prevent collapsing. Next, a metal cradle constructed with heavy I-beams is welded together and concreted into the floor for the entire length of the working undercut to the tunnel face. The working undercut and cradle are important as they make up the main staging area to accept and install the TBM. The TBM is brought to site on a large flatbed truck and trailer, and is lifted, lowered down the working shaft, and placed on the cradle in the working undercut typically by a 140-ton crane. The TBM is then pulled forward on the cradle with chains to the tunnel face. The TBM is then assembled by heavy duty mechanics over roughly 2 weeks. Electricians then come to site to connect a high-voltage power service that is supplied by to the TBM's power transformers underground, using a very large-gauge power cable (mole cable). A final mechanical check and survey for tunnel alignment is completed before excavation takes place. The face boards are removed and the TBM is launched into the ground carefully to make sure tunnel alignment is not compromised. The TBM excavates the dirt at the face and a single train, with usually 4 dirt cars, accepts the excavated material from the conveyer, travels back to the working shaft, and is taken up the working shaft and dumped by a smaller sized crane (usually 75 ton). This section of the TBM tunnel is called the 50-meter start up tunnel, as the TBM will excavate until the 50-meter mark and stop. From here, the remaining conveyer sections are installed and the power transformers are placed on top of a gantry that is dragged behind the TBM by chains. The dirt train and cars all fit underneath the gantry, which accepts the dirt from the extended conveyer unit. The working undercut is now outfitted with a wooden platform on which the train tracks are placed. A switch is installed to allow 2 trains with 5 cars to sit in the working undercut at the same time. Now, as one train exits the tunnel loaded with dirt from the TBM and passes the switch, the other train can enter the tunnel and begin being loaded by the TBM. The other train is unloaded by the crane simultaneously, so as to not hinder production of the TBM. During the time that the train is traveling back to the working undercut, the TBM is installing its concrete segmental liner around the outside of the tunnel diameter to support and finish the tunnel excavation. Once the switch is installed and the wood platform is completed in the working undercut, the main TBM tunnel excavation commences.

Figure 1: Trenchless TBM Tunnel Components and Initial stages of Tunnel Excavation

Prior to the completion of the TBM tunnel, the removal shaft and removal undercut has to be completed to accept the TBM and eventually disassemble and remove it. These components are completed in the same manner as the working shaft and working undercut, with the exception of the removal undercut being shorter in length than the working undercut, as it is usually only 9 meters in length. Once the TBM is removed from the removal shaft by the 140-ton crane, usually, hand excavated connection tunnels need to be excavated to connect an existing tunnel structure to accept flow in to the new tunnel and then connect again at the opposite end of the tunnel to release flow. These hand tunnels range anywhere from a few meters in length to upwards of 20 meters in length. The connection tunnel is usually of a smaller diameter than the main TBM tunnel and is excavated 1 meter length at a time and lined with metal rib and lagging. Once the existing pipe structure is reached and exposed, the hand tunnel needs to be finished typically with cast-in-place formed concrete. Once the concrete is cured, the entire length of the tunnel is inspected, and any variances are patched with concrete. The working undercut now has the concrete segments banded together in a circle and hand installed for the entire 30-meter length working undercut back to the working shaft location. The bottoms of both shafts are finished with cast-in-place concrete to finish the tunnel and seal the hand connection tunnels to the TBM tunnel. Once this is completed, the existing pipe is cut out (breaking out) at the downstream end first, then at the upstream end to accept flow into the new tunnel for the first time. Manhole barrels are now placed on top of the undercut structures and are stacked up to the ground surface where a manhole cover is placed on top. Fillcrete is poured around the outside of the manhole barrels to seal the gap between the inside of the removal shaft and the manhole. The tunnel is now complete.

5. SIMULATION OF TBM TUNNEL CONSTRUCTION

The tunneling simulation model follows the same process that was explained in the previous section. The model is generally driven by historical data collected for similar tunneling situations. The special purpose simulation model for this problem is illustrated in Figure 1, which shows the major components of the tunnel construction. In special purpose simulation, discrete modeling elements such as work-tasks are added inside these components to accurately reflect how the previously described construction process takes place. The process is therefore flexible to enable a user to make changes to processes taking place for specific projects. These discrete tasks are fitted with durations using standard statistical distributions. The discrete tasks also have labour, equipment, material, and other cost data added to each of them. By providing such information to the tunnel objects, a project estimate can then be produced in standard construction form. Simple processes such as building the shaft liners can generally be modeled with deterministic duration as they do not vary much, while critical path tasks such as the TBM excavation use a fitted distribution, as many factors affect its value for a particular iteration. A statistical distribution, carefully collected from historical data, provides a reasonable approximation for such tasks.

5.1. Tunneling Special Purpose Template Modeling

The tunneling template is a special purpose template developed in Simphony to simplify planning and analysis of tunnel construction projects (AbouRizk, 2013). The template is comprised of modeling elements, most of which represent the different physical components and resources that exist within a typical tunneling project, for example: a shaft element, tunnel element, crane (site) element and TBM element. The template is made up of modeling elements developed in Visual Studio.NET using Simphony services. The elements resemble the real-life items they represent, making template building easier for users not familiar with simulation. The modeling elements model the process of tunneling operation by capturing resources, scheduling events and releasing resources, collecting statistics or controlling work and non-work times. The template uses a hierarchical approach for design and implementation to match the complex nature of the process.

The templates have two parent-level modeling elements and eleven child-level elements. To model, the user can drag and drop the modeling elements, then align them in a pattern that represents the actual tunnel construction sequence (see Figure 2 for a typical model layout). The modeler can experiment with the template by inputting project information (work method - hand excavation, TBM excavation), project site conditions (depth of tunnel, tunnel diameter, tunnel length, geotechnical conditions along the shafts and tunnel, penetration rates in various ground conditions) and details on resources (number of trains, number of carts). Weather and work shifts (calendar) can also be customized. The individual template modeling elements allow for input of information before simulation and provide results after simulation. Figure 2 shows sample screen shots of the input/output interface. The template simulates the construction of the tunnel based on the information input and output results (i.e. costs, project duration, resource utilization, waiting times, daily advance rates, and volumes of earth excavated and handled). The template also models different dynamics and uncertainties experienced in a typical tunneling project such as equipment breakdown, bad weather interruptions and the details of work shifts – work times, breaks, overtime, weekends and holidays.

6. INPUT MODELING IS A CRITICAL PART OF SPECIAL PURPOSE SIMULATION

Although SPS is quite easy to use and provides good efficiency in building models, one of the significant requirements is accuracy in the input models. For TBM tunneling, given the linear and repetitive nature of the work, errors in the input models could easily produce incorrect results. In providing the service to clients, we have developed techniques that ensure good input models. These are discussed in this section.

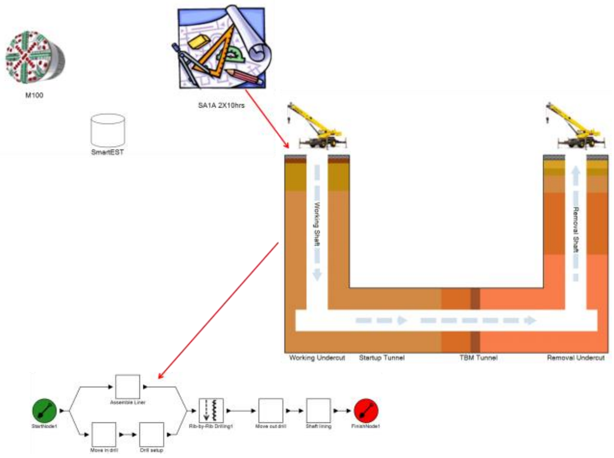


Figure 2: Special Purpose Simulator for Tunneling

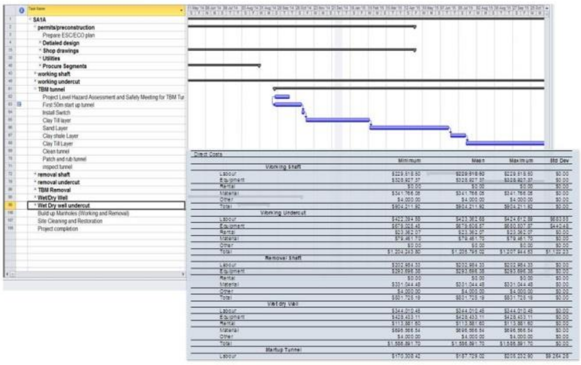


Figure 3: SPS Analysis Driven By Simulation but Product in Standard Form MS Project and SmartEst

6.1. Breakdowns/Interruptions

For this application, the critical path tasks were obtained through a Method Productivity Delay Model (Adrain and Boyer 1976) (MPDM) for which a project's delays/breakdowns are categorized and analyzed. The results of the MPDM analysis were fitted to distributions to show the overall delay time, ideal, and method productivities. The ideal productivity is the non-delay productivity that would have been realized if all the delays that occurred were removed. The method productivity is simply the ideal productivity with the delay categories reapplied to it. Each delay category can then be applied in the model as a breakdown element that governs the ideal productivity rate of the excavation.

We have fitted distributions to data representing breakdowns in the process referred to as "interruptions" in the model. We have split the interruptions into two categories: minor interruption and major interruption. A minor interruption is one that lasted between 0.5 and 3.5 hours (less than half a shift) prior to the process resuming its operation, while a major interruption is one that lasted between 4 and 10 hours (half to a full shift). Using statistical analysis, we determined the mean delay time for a minor and major interruption, as well as the mean time between minor and major interruptions. These results were each fitted to a distribution for use in the simulation model. The fitting process used @RISK to select the data and then determine the best fitting distribution. This was completed by producing a cumulative ascending graph for which the distribution was visually selected using the Bayesian Information Criterion (BIC). The minor breakdowns had a beta distribution fit with shape parameters of 2.0 and 2.0, and range parameters of 1.0 and 4.0, as shown in Figure 4.

The distribution for the time between the occurrences of minor breakdowns is an exponential distribution with a mean of 26.591 hours. The major breakdowns had a beta distribution fit with shape parameters of 2.0 and 5.0, and range parameters of 5.0 and 10.0, as shown in Figure 5.

The distribution for the time between the occurrences of major breakdowns is an exponential distribution with a mean of 41.189 hours. These distributions were placed into Simphony, inside the TBM element, as this is the excavation method and always lies on the critical path.

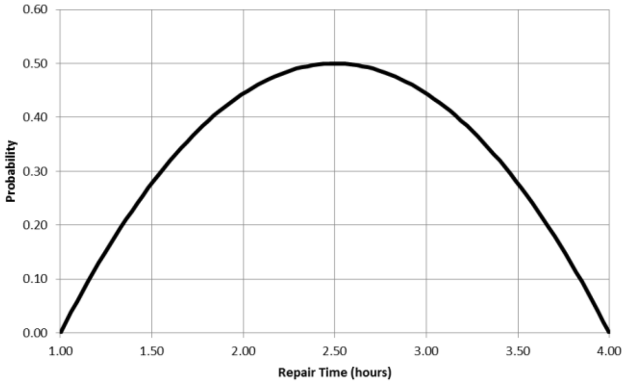


Figure 4: Minor Breakdown Distribution

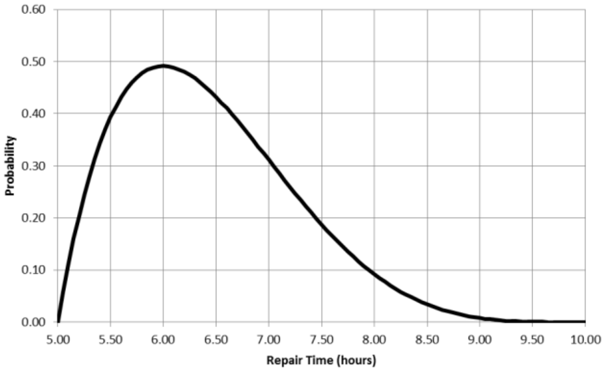


Figure 5: Major Breakdown Distribution

6.2. TBM Penetration Rates

Penetration rates for each ground condition have been sampled from the Method Productivity Delay Models (MPDM) studies conducted on various projects. The MPDM studies collect every delay that has occurred on a particular project and categorize it. These categories are then compared, in hours of delay, to the overall project working hours to obtain a percent delay time. The ideal productivities for similar ground types were used as the penetration rates. The ideal productivity is the productivity that would have been achieved if no interruptions had been realized. Adding this was essential for not double counting for interruptions when simulating.

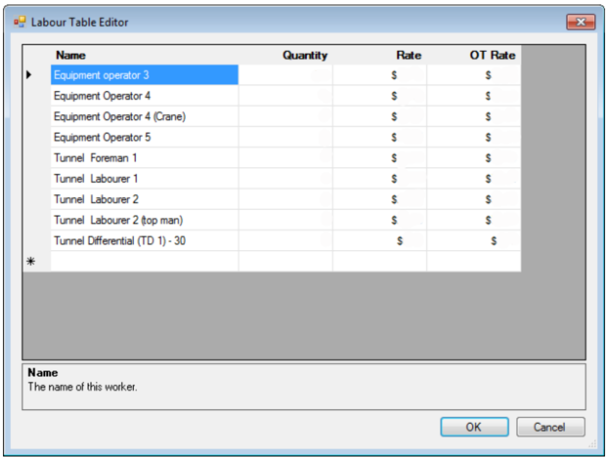
TBM penetration rates have been governed by surveying intervals to accurately reflect productivity and cost. Surveying has been broken down into 2 categories, laser calibration and moving the laser forward. The surveying duration is beta distributed with shape parameters of 9 and 2, and a range of 60 to 420 (measured in minutes). This distribution will be sampled every 60 meters of excavated common earth. When excavating in material that is predominantly sand, the distribution will be sampled every 15 meters, as there is a higher probability the installed segment liner that the laser is fixed to will settle, causing the laser itself to be misaligned. There is also a higher probability that the TBM creates a void in the ground either above or below the excavation face, which will shift the excavating alignment of the TBM. A curve in the tunnel alignment will drastically alter the surveying intervals. Curved sections will have a laser movement interval every 6 meters, which will constantly take 420 minutes or 7 hours to complete. Soil swell factors also have been accounted for in the special purpose tunneling model. This will affect the rate at which the TBM fills the dirt car trains as bank ground measurement is converted into loose ground measurement. A higher swell material will mean less ground penetration by the TBM and more frequent train travel as the dirt cars fill up faster. The amount of excavated dirt volume and swell factors are displayed for each tunnel ground type. This will also mean that the TBM will sit idle for longer as it is waiting for the train to return.

6.3. Unit Rates for Estimates

The SPS provides very easy-to-use features that incorporate estimation into the simulation environment through unit rates. With the use of the SmartEst database, crews are stored with their unit rates. A regular time and overtime rate is provided and will automatically be used according to the type of calendar specified in the scenario. This provides us with the added flexibility to also manually adjust the unit rates or add resources to the table with their corresponding unit rate. By looking at the client’s actual charges from a past project, we can update these unit rates within SmartEst to provide accurate year-to-year estimation that is not impacted by inflation. We have revisited and reset proper unit rates to all of the indirect charges associated with the tunneling projects.

Indirect charges for the project appear in the high-level project icon. These are also added through SmartEst, but can be manually entered. By checking the percentage box, this means that the particular indirect cost will be estimated using the percentage entered in the value column. If the percentage column is not checked, then the value entered in the value column will be a fixed dollar value added to the project.

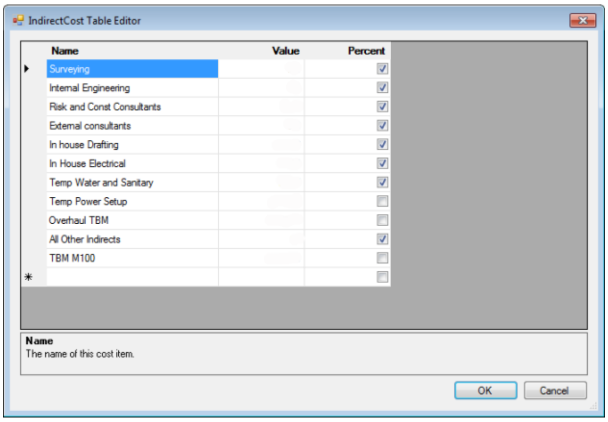
Common areas of concern for estimating projects can be easily reconfigured in the SPS. These work packages can be given new unit rates that reflect actual performance based on past projects. Overall, the estimate will be a much more accurate representation of how the project will materialize as the simulation models the delays previously mentioned and adjusts the estimate accordingly.



Name	Quantity	Rate	OT Rate
Equipment operator 3		$	$
Equipment Operator 4		$	$
Equipment Operator 4 (Crane)		$	$
Equipment Operator 5		$	$
Tunnel Foreman 1		$	$
Tunnel Labourer 1		$	$
Tunnel Labourer 2		$	$
Tunnel Labourer 2 (top man)		$	$
Tunnel Differential (TD 1) - 30		$	$

Name
The name of this worker.

Figure 6: SPS Crew Estimation Table



Name	Value	Percent
Surveying		☑
Internal Engineering		☑
Risk and Const Consultants		☑
External consultants		☑
In house Drafting		☑
In House Electrical		☑
Temp Water and Sanitary		☑
Temp Power Setup		☐
Overhaul TBM		☐
All Other Indirects		☑
TBM M100		☐

Name
The name of this cost item.

Figure 7: SPS Indirect Cost Estimation Table

7. SIMULATION AS A SERVICE

This paper describes an innovative approach for applying simulation as a service. In this research, simulation is designed specifically for application to a utility tunnel construction project and customized to meet client output needs, using a special purpose simulation approach. The model outputs the information required by the client in a format that is usable for them. This provides the client with decision support information to make their operations more efficient and effective. Additionally, tools such as value engineering and constructability reviews help the client to obtain more accurate estimates and schedules in the project planning stage.

In general terms, simulation tools are effective in modeling tunnel construction, especially because such processes are linear in nature and are composed of repetitive sub-processes. The challenge is to have the decision maker justify the investment in time, resources and costs associated with building a simulation model for smaller tunnel projects (those that are less than $50 million in cost). For larger projects, the capital investment is significant and the planning time is long, thus providing ample opportunities for deploying simulation in planning the project.

Typically, construction planners rely on two elements once a preliminary design has been produced: the construction costs and the schedule associated with a particular option. Those two elements guide them in selecting the final construction alternative for the project. The simulation in itself is therefore not an end result for a construction planner. It could simply be the means to produce costs and schedule information for decision support. More specifically, schedules are expected to be in a CPM format, and costs in a work-package model, consistent with the models the company uses.

The first author adopted the simulation tools to produce the costs and schedule for clients. First, simulation modeling normally generates more accurate production information, which is the essence of cost and schedule. Second, if special purpose simulation is used, the development time and the consistency by which estimates and schedules can be produced to reflect varying alternative tunnel plans can be significantly reduced, as compared to developing estimates using standard software or schedules using CPM software. Furthermore, since the base model is the same, the estimate and schedule are based on the same foundation, whereas in practice, they are generally developed by different people on different bases.

The consulting firm where the first author works, has applied the above strategy to the modeling of tunnel construction by adopting a special purpose simulation model. The SPS model provides a quick turnaround time, and is a cost effective service to the client, and at the same time, takes advantage of what simulation has to offer in its accuracy of predictions. SPS provides the flexibility to integrate its simulation environment with a basic service that the client may require, such as estimating, scheduling, pre-project planning, or a constructability review. With the SPS, we custom link the simulation of any project with these tools while building the project schedule and estimate in Microsoft Project and SmartEst, respectively. The model is built around the work breakdown structure (WBS) of the project and provides detailed information about each work package. After the WBS is defined, the modeling elements are placed inside their work packages, as shown in Figure 8.

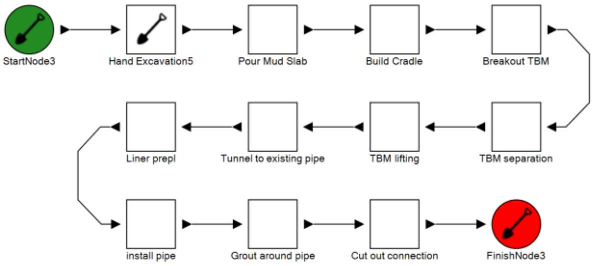


Figure 8: Modeling Elements inside the Removal Shaft Work Package

Each of these modeling elements inside the work packages has its own unique scheduled durations and crew costs. These modeling elements together create their work packages' cost and schedule duration. This is summarized in a summary report that will show the client the start and finish date of each element, the hours needed to complete the element, its resulting daily productivity, and the estimated cost. It should be noted that this summary sheet is particularly unique for this single simulation.

After the client has selected its preferred level of risk, the cost and duration of this work package is added to the overall project. The client can then take these results to a value engineering or constructability session, to provide key decision support to the project team. The project team will then be able to better create different scenarios to construct the project. The scenarios can then be added to the original model to provide further decision support to the project team. Further scenarios can be run to alter the type of shift that the project team needs to hit any certain cost or schedule constraints. The shift change scenarios will be able to show the client any cost/schedule trade-offs that may exist to further provide added value.

The model output provides a schedule (start/finish dates) and cost for each phase of the project as a distribution.

8. CASE STUDY APPLICATION

Note: all numbers presented in this case study were scaled and names were removed for confidentiality.

8.1. Project Background

The Project X TBM tunnel project is a 630 meter tunnel that is part of the Project A line. The tunnel is to be constructed using the M100 TBM. The tunnel is located along a road, where the working shaft is placed in a parking lot and the removal shaft is located near the pump station at an intersection. A hand excavated connection tunnel will be constructed to connect to the pump station.

Figure 9: Project X Location

8.2. Objectives and Approach

The objective of this analysis is to establish production targets, assess feasibility of the project schedule and budget, and establish a base plan for the construction phase of Project X. To achieve those objectives, construction process simulation models were developed, required information was collected and an analysis carried out.

8.3. Simulation Model

The TBM tunnel model is composed of 10 major work packages, each with their own properties and parameters that have been derived based on information presented in the geotechnical reports, from historic data, or from expert opinion. These include: working shaft, working undercut, startup tunnel, tunnel excavation, removal shaft, removal undercut and connection tunnel.

8.4. Assumptions within the Simulation Model

The simulation models assume the following:

- Double shifts for every task during construction.
- All drawings are completed 1 month in advance to constructing the element.
- The working undercut is two-way hand tunneling.
- The tail tunnel working undercut is half completed under the previous hand tunnel and not part of the TBM tunnel scope.
- Mixed faces are to be encountered between tunneling layers.
- The removal shaft and undercut start during TBM excavation.
- The M100 TBM is charged out at a rate of $298/meter excavated.
- The unit rate for the precast segments is $1,008.00/linear meter.
- The connection tunnel and hand installing working shaft segments happen at the same time.
- Building up the manholes, one shaft after another, occurs after opening up the tunnel, assuming all other Project X components are completed prior to finishing the TBM component.
- Most construction risks have been incorporated in the model except for catastrophic events, and contingency.

A number of simulation scenarios were run. All scenarios were run multiple times as is the standard in Monte Carlo simulation techniques.

8.5. Base Scenario

The base scenario is composed of a single 8-hour shift that has 2 trains operating with a switch. Under this scenario, the entire project is expected to finish within 2 years, with a total mean cost of approximately $7,914,347.

The individual work package schedules are as follows. The working shaft would be complete in 20 working days. The working undercut takes 91 working days to complete. The simulation estimated an average of 0.340 meters per shift per tunnel, which includes delays, break downs, etc. This is justified as the undercut sections are usually split in to digging the top section and installing the ribs and lagging, then the bottom section with lagging and spreader.

The TBM in clay takes 33 working days to complete. The average productivity is 0.92973 meters per shift. Layer 1 clay takes 41 working days to complete. The average productivity is 2.4786 meters per shift. Layer 2 clay till takes 40 days to complete. The average productivity is 2.71278 meters per shift. Layer 3 clay takes 14 working days to complete. The average productivity is 2.5000 meters per shift. Layer 4 sandstone takes 89 working days to complete. The average productivity is 2.6337 meters per shift.

The removal shaft takes 20 days to complete excavation. The removal undercut takes 72 working days to complete. The undercut excavation productivity is 0.4259 meters per shift. TBM removal will take 13 days to complete. The connection tunnel takes 47 days to complete. The productivity for the excavation is 0.7994 meters per shift. Building up the man holes for both the working and removal shafts takes 14 working days.

Throughout the tunnel excavation, the TBM was idle for 4.5% of the total work hours. A summary of the TBM tunnel work package productivity by layer is given in Table 1.

Upon presenting the base scenario to the client, the director of construction asked to have the models run so that the construction of the project meets the promised requirements. The following scenarios were produced as summarized in the section below. Two scenarios were run, the first with two 8-hour shifts and the second with two 10-hour shifts. Both had two trains operating with a switch in the working shaft area.

Table 1: Single 8-Hour Shift TBM Productivities by Soil Layer

Work Package	Section	Length (m)	m per shift	Advance per day	Days Required
Tunnel	Start-up (clay)	36.26	0.9297	0.9297	33
	Clay	119	2.4792	2.4791	41
	Clay till	128	2.7128	2.7127	40
	Clay shale	43	2.5000	2.4999	14
	Sand stone	292	2.6337	2.6336	94
				Days	223

9. CONCLUSION

The SPS makes it possible for simulation to provide a value-adding estimate and schedule solution to the construction industry as a whole. This provides the client with decision support information to make basic client services more efficient and effective. Services such as value engineering and constructability reviews can have multiple project scenarios created for them to allow the client to get more accurate estimates and schedules in the project planning stage. The key to SPS is the data input to the model. Proper background work is needed from past benchmarked projects to act as verification and validation of the model to its intended application.

REFERENCES

AbouRizk, S.M. and Hague, S. 2009. An Overview of the COSYE Environment for Construction Simulation. *Proceeding of the 2009 Winter Simulation Conference*. Rossetti, M.D., Hill, R.R., Johansson, B., Dunkin, A., and Ingalls, R.G., eds., IEEE, 2009, 2624-2634.

AbouRizk, S.M., and D. Hajjar. 1998. A framework for applying simulation in the construction industry. *Canadian Journal of Civil Engineering*, CSCE, 25(3): 604-617.

AbouRizk, S.M. 2013. Innovations in tunneling construction management applications of simulation. *Proceedings of the EURO:TUN 2013*.

Adrian, J. and L.T. Boyer. 1976. Modeling method productivity. *ASCE Journal of the Construction Division* 102(1):157-168.

Chang, D. Y., and Carr, R. I. (1987). “RESQUE: a resource oriented simulation system for multiple resource constrained processes.” PMI Seminar/Symposium, Milwaukee, WI, USA, 4-19.

Einstein, H. H. 2004. The Decision Aids for Tunnelling (DAT) – An Update. *Transportation Research Record* (1892), 199-207.

Haas, C. and Einstein, H.H. 2002. Updating the Decision Aids for Tunnelling. *Journal of Construction Engineering and Management*, ASCE, 128(1), 40–48.

Hajjar D. and AbouRizk S. M. 1999. Simphony: An environment for building special purpose construction simulation tools. *Proceedings of Winter Simulation Conference* 2. IEEE: New Brunswick, NJ, 998-1006.

Halpin, D.W., 1977. CYCLONE: Method for Modeling of Job Site Processes. Journal of the Construction Division, ASCE, 103(3) , 489-499.

Ioannou, P.G. 1988. Geological Exploration and Risk Reduction in Tunnelling. *Journal of Construction Engineering and Managemen*t, ASCE, 114(4), 532-547.

Martinez, J., and Ioannou, P. G. 1994. General Purpose Simulation with Stroboscope. Winter Simulation Conference, ASCE., San Diego, CA, USA, 1159-1166.