SPS TOOLS FOR CAPITAL PLANNING PROJECT ANALYSIS

Nathan Boskers[a], Simaan M. AbouRizk[b]

[a] Springwood Developments Ltd.
[b] University of Alberta

[a] nathan@springwood.ca, [b] abourizk@ ualberta.ca

ABSTRACT

This paper presents the development of a special purpose simulation (SPS) template for the capital planning on large-scale infrastructure construction projects. The template targets outputs of greatest interest to the planner: project duration and cost estimate, using the Box Jenkins method of forecasting. The developed tool was then tested in a case study involving roadway restructuring in Edmonton, Canada. The case study is detailed here for purposes of illustration. Seven models were simulated and analysed, showing the relative influence of fixed rates and mean rates on forecasting, and that subjective analysis procedures can cause disadvantageous decision-making. The case study was also used to perform risk analysis for the City of Edmonton.

Simulation models; intelligent forecasting; capital projects; construction project planning

1   INTRODUCTION

Computer simulation is the process of designing a mathematical-logical model of a real world system and experimenting with the model on a computer (AbouRizk et. al. 1995). Computers ideal tools for modeling real world systems because they can process large amounts of data in short periods of time. Halpin developed the first simulation model for construction purposes around 1973 (AbouRizk et. al. 1992). The developed model was called CYCLONE, standing for cyclic operations networks. The CYCLONE models were based on resources and their interactions with each other.

Due to the success of CYCLONE, much further research was done in the area of computer simulation for construction purposes. Some researchers enhanced CYCLONE, or developed new models, such as INSIGHT, UM-CYCLONE, and others. Carr (1979) developed a system called MUD (Model for Uncertainty Determination). This model simulated network scheduling to estimate activity durations. Dabbas and Halpin (1982) developed a similar simulation, which estimated activity durations, by combining the CYCLONE and a CPM scheduling software system. Lutz and Halpin (1990) developed a simulation to monitor process cycles and stage buffers using microCYCLONE. Liu and Ioannou (1992) developed a discrete-event simulator system, which used an object-oriented design. The simulator could track resources, construct models using a graphical interface, capture resources, define different resources, and link with other planning systems. The system they developed was called COOPS (Construction Object-Oriented Process Simulation System). A knowledge-based simulation was created by Odeh et. al. (1992), called CIPROS. This system was an object-oriented system used for developing discrete-event simulation networks. The CIPROS system enabled users to relate construction plans and specifications to a construction plan.

For project selection purposes, Ruwanpura et. al. (2002) developed a Special Purpose Simulation (SPS) tool. The SPS tool incorporated influence diagrams, with the various components representing the input data. The project parameters were analyzed using Monte Carlo analysis, and a project NPV distribution was produced. Again, like the methods developed by Ye and Tiong (2000) and Lu et al. (2000), a confidence level was used on the NPV distribution to determine the projects attractiveness. Ye and Tiong's study into the various project analysis methods showed that the NPV method is the most suitable method. This can be verified by the NPV method's wide use in industry and in current research. As well, Monte Carlo analysis has become widely used and accepted as a method to account for uncertainty in project costs.

Hajjar and AbouRizk (1999) developed a simulation environment called *Simphony*, for the purpose of building special purpose simulation (SPS) tools. AbouRizk and Hajjar (1998) defined SPS as a computer-based environment built to enable a practitioner who is knowledgeable in a given domain, but not necessarily in simulation, to model a project within that domain in a manner where symbolic representations, navigation schemes within the environment, creation of model specifications, and reporting are completed in a format native to the domain itself. Special purpose simulation (SPS) tools developed in *Simphony* have proven to be very useful for the purposes of analyzing and optimizing capital investment projects. Templates created in *Simphony* use modelling elements for the purpose of

building project specific simulation models. The planning template has seven modelling elements. Each modelling element contains all, or a combination of, input parameters, outputs, and statistics. In some cases, modelling elements can obtain input values from other elements on different hierarchical levels, as well as report outputs to other modelling elements on different hierarchical levels.

With respect to capital investment projects, project analysts have a great need for accurate knowledge of future cash flows. Future cash flows are used to make important decisions, such as the procurement method to use for the construction phase of a project, or what kind of financing should be used for a project, and so on. With the aid of accurate forecasting techniques, such as simulation, cash flow analysis can be done more objectively, which will result in the ability to make more informed planning decisions.

2 BOX JENKINS FORECASTING

The Box-Jenkins methodology for forecasting is used for the purposes of forecasting non-stationary time-series. A non-stationary time-series is simply a time-series that has changing parameters over time (i.e. the mean and variance are not constant). The Box-Jenkins methodology suits itself well to capital investment project planning, or overall lifecycle project planning in general, because such things as Consumer Price Indexes (CPIs) and Construction Price Indexes, which are used in forecasting cash flows, are by nature non-stationary time-series. Hence, the Box-Jenkins forecasting techniques can be well utilized for the forecasting of those indices.

Before an understanding of the steps of the Box-Jenkins methodology is possible, a general understanding of stationary time-series analysis is required. Next, stationary time-series analysis will briefly be discussed. The Box-Jenkins model is for analyzing non-stationary time-series. The Box-Jenkins model simply combines the idea of differencing and the ARMA model into one single model, called the Autoregressive Integrated Moving Average (ARIMA) model. The general ARIMA model can be defined as the following:

$$\phi_P(B)Y_t = \theta_q(B)a_t \tag{1}$$

where

$$Y_t = \begin{cases} (1-B)^d(1-B^s)^{d1} z_t & \text{if } d > 0 \text{ and/or } d1 > 0 \\ \\ z_t - \mu & \text{if } d = 0 \text{ and } d1 = 0 \end{cases} \tag{2}$$

The general ARIMA model can be expressed as ARIMA (p, d, d1, q).

An addition to the general ARIMA model can be added to incorporate a seasonality component into the model. Seasonality implies a repeating pattern in the time-series over a seasonal cycle. This type of pattern is incorporated into the ARIMA model as follows:

$$\phi_p(B)\phi_{p1}(B^s)Y_t = \theta_q(B)\theta_{q1}(B^s)a_t \tag{3}$$

where Y_t is the same as for the general ARIMA model.

The complete ARIMA model is then expressed as ARIMA (p, p1, d, d1, q1, q).

2.1 Box Jenkins Methodology

Using the techniques described above, four steps can be followed to aid in the task of forecasting future cash flows. The four steps are: 1) model identification, 2) parameter estimation, 3) diagnostic checking, and 4) forecasting. Figure 1 shows how these steps are carried out.
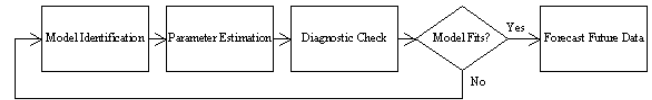

Figure 1: Box Jenkins forecasting methodology

2.1.1 Step 1: Model Identification

The first step in the Box-Jenkins methodology involves determining a tentative model to use in the succeeding steps of the methodology. In order to determine the parameters of the tentative model, the analyst must analyze the plotted data series, the plotted SACs and the plotted SPACs. Using these plots, the analyst must first determine the amount of differencing required, and then from this differenced model, determine the amount of regular and seasonal back shift that is required.

To determine the amount of differencing to use, the analyst should generate many combinations of SACFs and SPACFs by using various combinations of d and d1 values. Many plots should be generated, as the analyst does not know beforehand which differencing is required. As mentioned earlier, if a series is stationary, the plot of data will not have an increasing or decreasing mean, and the SACF and SPACF will tend to dampen quickly.

To determine the orders of the ARIMA model, reference tables can be used. The decision on the ARIMA parameters is subjective, so a few tentative models may be chosen to carry through to the next steps.

2.1.2 Step 2: Parameter Estimation

The next step in the Box-Jenkins methodology is to estimate the model's parameters ϕ and θ. The most appropriate values for the parameters are those that minimize the residuals of the model, a_t. The residuals represent the difference between the actual historical data points, and the estimated historical data points using the tentative ARIMA model with estimated parameters, i.e. $a_t = z_t - \hat{z}_t$. When the residuals are minimized, the tentative model produces results most similar to the actual historical data.

The most efficient means of obtaining the parameter estimates is by utilizing a computer program. The procedure for determining the parameters is basically a nonlinear optimization problem. The objective function of the problem is to minimize the sum of the residuals squared, i.e. a_t^2, and the decision variables are the values of the model parameters. The reason a computer program is needed to perform this analysis is due to the many iterations required to test the parameter estimates. Due to the problem being iterative in nature, initial estimate values for the parameters are required for the first iteration. Gaynor and Kirkpatrick (1994) suggest using 0.1 as a good starting value for all ϕ s and θs being estimated.

2.1.3 Step 3: Diagnostic Checking

The third step in the Box-Jenkins methodology is to test the tentative model with the estimated parameters for its closeness of fit, which is done by running tests on the residuals, a_t. The test that is used is the Chi-Squared test.

The Chi-Squared test checks to see if there is any systematic error in the residual SAC. The first step in performing the Chi-Squared test is to calculate the test Chi-Squared statistic, Q, as follows:

$$Q = n\sum_{k=1}^{K} r_k^2(\hat{a})$$
(4)

where n is the total number of observations minus the maximum back shift, K is the number of residual SAC values that have been calculated, and $r_k^2(\hat{a})$ is the residual SAC of the series $(\hat{a}_t)$ at lag k. The second step in performing the Chi-Squared test is to determine a Chi-Squared distribution, X^2 with K-p-q degrees of freedom, where p and q are the AR and MA orders. The third and final step is to compare the calculated value Q versus the Chi-Squared distribution X^2. If Q is greater than X^2, the model is inadequate, and if Q is less than X^2, the model is adequate.

If the Chi-Squared test failed, further improvement to the tentative model is required. The analyst must determine how to improve the model and repeat steps 1 through 3 over and over until an adequate model is obtained. The first thing the analyst should do is look at the pattern of the SACF of the residuals obtained in step 3. This pattern will help indicate the improvement required for the inadequate model. For example, if the SACF shows a large spike at the first lag, yet no MA order is present, this is a good indication that a MA with q=1 should be added to the model.

2.1.4 Step 4: Forecasting

Once an adequate model has been determined, the analyst can proceed with the final step of forecasting future data. Using the determined model, the ARIMA model equation is rearranged to solve for z_t. In order to better demonstrate how this process works, consider an ARIMA (2, 0, 1, 0, 0, and 0) model. Also, assume that the parameters were estimated to be $\hat{\phi}_1 = 0.25$ and $\hat{\phi}_2 = 0.45$. The model would be written and rearranged as follows:

$$(1 - 0.25B^1 - 0.45B^2)(1 - B)^1 z_t = a_t$$
(5)

$$(1 - 1.25B^1 - 0.2B^2 + 0.45B^3)z_t = a_t$$
(6)

$$z_t = 1.25z_{t-1} + 0.2z_{t-2} + 0.45z_{t-3} + a_t$$
(7)

Converting equation (7) into a forecasting equation, let T be the current time period, and l be the period in the future at the end of the current period. Equation (7) then becomes:

$$\hat{z}_T(l) = 1.25z_{T+l-1} + 0.2z_{T+l-2} + 0.45z_{T+l-3} + a_{T+l}$$
(8)

Equation (8) can then be used to forecast the desired future data from the historical data.

3 MODELLING ELEMENTS

3.1 Input Parameters

The input parameters in the modelling elements are parameters that require the template user to manually enter a value. The inputted values will be used by the template to calculate the output. All the modelling elements and their respective inputs are listed in Table 1.

The project planner element is the highest element on the hierarchical structure of elements. The input parameters required in this element are those that are related to the overall project analysis. For example, the discount rate value is entered as a percentage in this element. As well, outputs generated from the modelling elements on lower hierarchical levels are reported to this element and used as input. The project planner has the

following input parameter (see Table 1) for simulation: Discount Rate (%). The discount rate value is what is used in the computation of the overall project's NPV.

Table 1: Modelling elements with input variables

Modelling Element	Description of the Input Variable	Deterministic (D) or Stochastic (S)		Subjective Variable
		D	S	
Project Planner	Discount Rate (%)	X		
Collector	Collector Description	N/A	N/A	
	Overhead (%)	X		
Activity	Model Duration?	N/A	N/A	Yes/No
	Forecast Type	N/A	N/A	Select from list
	Activity Description	N/A	N/A	
	Activity Duration		X	
	Activity Direct Cost ($)		X	
	Activity Indirect Cost ($)		X	

The collector element is the element used to represent a project's work package. This element is below the project planner element in the hierarchical structure, but above the activity element. The input parameters in this element relate to the sub-work packages and activities inside the given work package. The collector element has the following input parameters (see Table 1) for simulation: Collector Description, and Overhead (%). The overhead input parameter is entered as a percentage number, and is multiplied by the total costs obtained from the outputs of the elements in the lower hierarchical levels. The purpose of this input parameter is because often times at the conceptual planning stages of a project, the overhead cost estimate ("overhead" meaning such things as project office staff and other office resources) is given as a percentage of the direct project work package cost.

The activity element is the element used to represent a project's activities. This element is below the collector element in the hierarchical structure. The input parameters in this element relate to the costs and durations of the activities. The input parameters entered here affect the overall project analysis output. The input parameter duration affects the timing of all succeeding activities and succeeding work package, which affects the total project NPV. The input parameter cost affects the overall time period cash flow, which affects the total project NPV. The activity element has the following input parameters (see Table 1) for simulation: Model Duration, Forecast Type, Activity Description, Activity Duration, Activity Direct Cost, and Activity Indirect Cost.

The start, finish, in, and out elements are all used for the purpose of guiding the path of the simulation model. None of these elements have any input parameters.

3.2 Output and Statistics

The planning template performs calculations and computations to produce the desired output and statistics an analyst would use for the analysis of a project. *Simphony* allows the template designer to create template specific output and statistics if desired, as well as provides built-in functional features.

The only output in the planning template that is seen by the analyst is in the finish element. The output here was specifically incorporated into the planning template by the template designer, so that the analyst could determine the overall project finish time for each simulation run. The other output in the planning template is produced by *Simphony* and used as input in other elements, where it is needed for further computations. This output is irrelevant to the analyst, and so hence is not given in visual form.

The statistics that are calculated and represented in graphical form are all done in the project planner element. The first statistic is the NPV. The NPV is collected for each simulation run, and the statistics are calculated on the collected data. The statistics on the collected NPVs are used by the analyst to analyse the project. The statistics given then are the project's maximum, minimum, and mean NPV. In addition to this, a CDF is produced. The CDF is what the analyst can use as an indicator at a specific level of confidence to tell if the project is worth investing in or not. The final statistic is the project time. This statistic is generated for the purposes of knowing the possible ranges of the project duration, so that planning can be made accordingly.

4 CASE STUDY

The Yellowhead Trail and 156 Street Grade Separation project, which is owned by the City of Edmonton, was used for a case study to test the developed SPS tool. At the time of modelling this project, the project was at the conceptual design phase. The purpose of the study was twofold: first, to test the developed SPS tool, and second, to perform risk analysis for the City of Edmonton so that they could have a more reliable cost estimate for the project. A more accurate cost estimate would enable the

City to properly assign financial resources to the project, and not tie up any additional capital that would not be required.

The planning template is an SPS tool developed in the *Simphony* environment specifically for the purposes of analyzing and optimizing capital investment projects. The planning template has a graphical user interface that allows for the easy creation of capital investment project models. It can be reused over and over again for the analysis of countless projects.

Please note that this paper uses the term 'range estimate,' which should be understood as the application of Monte Carlo techniques to project costs and revenues.

4.1   Developed Cost Estimate Models

Seven models were developed for the analysis process. The first model was the fixed cost estimate provided from the City. This model did not incorporate any uncertainty, nor did it incorporate any future costs due to inflation. This model was used as the base model. The second model was the fixed estimate plus the incorporation of an inflation rate of 3%. The third model was a range estimate of the costs, without any inflation costs incorporated. The fourth model was a range estimate and network analysis model, with an inflation rate of 3%. The fifth model was a range estimate and network analysis model, with a forecasted inflation rate. The sixth model was a range estimate and network analysis model over a 15-year period, with an inflation rate of 3%. The seventh and final model was a range estimate and network analysis model over a 15-year period, with a forecasted inflation rate.

The first two models were used for the purpose of comparisons with the other developed models. These models are what current industry would use in project analysis. The first model does not incorporate any uncertainty, and assumes the inputs (future cash flows) are known with absolute certainty. As well, the first model does not incorporate any escalation costs due to inflation. The second model is the same as the first, except it incorporates inflation by subjectively selecting an inflation rate of 3%.

The third model developed was strictly a range estimate of the costs. This model was done using the Range Estimate Template in *Simphony*. The costs were in current dollars (today's dollars), and were directly inputted into the simulation model from the data that was provided by the City. The contingency value that was provided from the City for the CN Structure and the Yellowhead Trail Structure were not included in the estimate costs. It was assumed that the purpose of this contingency was to account for risk and uncertainty in the estimate values, due to the early stage of the design work. Since the purpose of range estimating analysis is to account for risk and uncertainty in project costs, it was

concluded that by including the contingency values, the risk and uncertainty associated with structure costs would be over accounted for.

The fourth model developed was done by creating a network model of the project's work packages and activities. The network model was based on the Microsoft Project bar chart schedule, provided by the City. In the analysis done, the work packages were defined by the 10 construction activities on the schedule. Activities were defined as work done inside each work package. Some assumptions had to be made as to which activities belonged to which work packages. It was assumed that the 'Excavation' and 'Fill' activities from the owner's estimate belonged to the 'Fill Placement' work package on the schedule. It was assumed that the '50mm Grind', '50mm Overlay', 'Slab-on Islands', and 'Clean & Grubbing' activities were part of the 'Paving Interchange' work package. It was assumed that the 'Landscaping' work package items 'Naturalized Wetland', 'Standard Turf', '150mm Topsoil', 'Wetland Fills', and 'Wetland Soils' would occur between April 1, 2004 and August 4, 2004. It was assumed that 'Formal Planting in Beds', 'Street Tree Planting', and 'Individual Axial Planting' activities would occur between July 1, 2005 and January 1, 2005. And finally it was assumed that 'Asphalt Trail', 'Benches', 'Picnic Tables', and 'Waste Receptacles' activities would occur between March 18, 2007 and October 1, 2007. The reason these assumptions had to be made was because of the escalation of costs due to inflation calculations that were performed on them. Varying the occurrence of an activity would subsequently result in altering the total project cost. As well, it should be noted that due to the lack of detail in the schedule provided, all activity costs occurring within a work package had to be spread evenly over the work package duration. For the fourth model developed, a subjective inflation rate of 3% was used.

The fifth model that was developed was identical to the fourth model developed, as explained above, except for one notable difference. The inflation rate that was used in this models analysis was not subjectively selected; rather it was forecasted using forecasting techniques. The same assumptions made in the network set-up from the fourth model were also assumed in this model. The results of this model are a project total cost in actual dollars.

The sixth model that was developed was identical to the fourth model developed, as explained previously. The difference between the fourth and sixth models was in the modelled project's time of occurrence. The fourth model was modelled to start August 1, 2002, while the sixth model was modelled to occur beginning October 1, 2011. This was done was to compare the long term effect of using a forecasted inflation (which is model seven) versus a subjective inflation rate (which is model six) on the total project cost.

The seventh and final model that was developed was identical to the sixth model, except that the inflation rate used here was forecasted using forecasting techniques.
It should be noted that all the input data used for all the developed models was provided by the City of Edmonton. The data includes durations, quantities, and costs, given as parameters for triangular and uniform distributions.

4.2   Analysis Procedure

Upon determining the project network sequencing, the project network was input into the developed SPS tool in the *Simphony* modelling environment for the discussed models. Figure 2 shows a graphical image of the network created at the highest hierarchical level. Once the network was inputted, all the project activity parameters, such as duration and cost, were defined. Once all the parameters were defined, all the developed simulation models were run for 100 simulation runs, and statistics calculations were performed on the collected data.
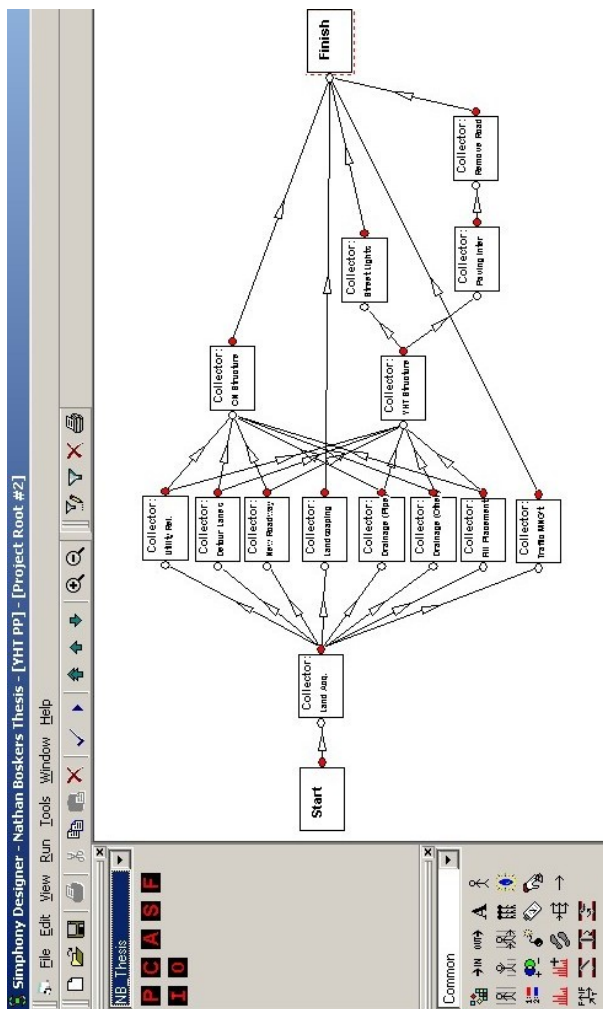

Figure 2: Case study network diagram

4.3   Summary of Simulation Results

The results of the simulation analysis are summarised in Table 2. Figure 3 shows the cumulative distribution function (CDF) for the range estimate plus forecasted inflation costs.
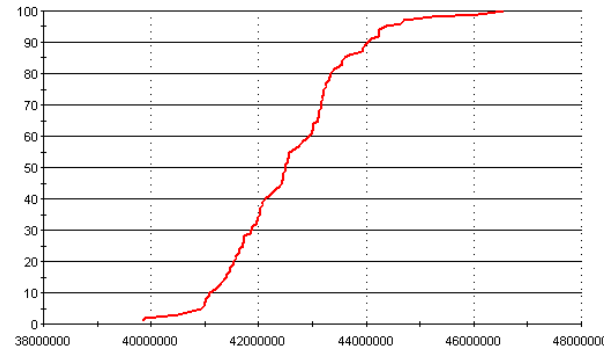

Figure 3: CDF for range estimate with forecasted inflation

4.4   Discussion

As indicated earlier, the purpose of the case study was twofold. The first reason was to test the developed SPS tool. Upon viewing the output of the seven models, some observations can be made. The first observation is that the mean range estimate costs for all cases are higher than the fixed estimate costs. This means that if the fixed estimate were used for budgeting purposes, the actual costs of the project would most likely be overrun. The second observation that can be made is that the forecasted inflation rate produced outputs that were consistently less than the subjective inflation rate of 3%. It can be observed as well, that as the project life increases (as in the case of the 15 year project), the difference between the total project cost for the forecasted model and the arbitrary model increases. This means that by subjectively selecting an inflation rate, the cash flows of the project can be significantly different from the cash flows of the forecasted rate. This could result in the analyst consistently overcompensating for the cost of inflation, or not compensating enough, depending on the subjective rate that is used. In the case study, the costs determined using the subjective rate would over account for the cost of inflation, and hence the City would budget more capital than necessary to the project.

The second reason for the case study was to perform risk analysis for the City of Edmonton. The results obtained indicated that the data provided by the City was not ideal in the sense that the fixed estimate totals were too similar to the range estimate totals. The main reason for this is due to the input data that was provided from the

City. For example, the work package 'Land Acquisition', which is the largest work package in value, was a fixed number, with no variance at all. Other large work package items had relatively small variance, which as well could contribute to the small overall project cost variance. According to a study performed by AbouRizk et al. (2002) for City of Edmonton projects, the suggested variance for preliminary design estimates for road construction should be + 25%. The results of the analysis show that the total project cost ranges from approximately $39.8 million to $46.6 million, with a mean of $42.6 million. The variance here is about $4 million, which is about 9.4%.

This actual variance determined from the analysis is much less than the suggested value made by AbouRizk et al. (2002). This implies that the input data provided by the City was not as generous in the size of the ranges as it should have been, considering the phase of the design. In order to ensure that the data provided for the input parameters for the project are accurate, the activities that make up 80% of the total project cost should be checked, as they are the activities that contribute most to the project's overall cost.

5   CONCLUSION

Range estimating and network analysis techniques were used to analyse the Yellowhead Trail and 156 Street Grade Separation project. Seven simulation models were developed for the purposes of testing the developed SPS tool, as well as performing risk analysis for the City of Edmonton. The output generated yielded some interesting observations, the first being that the fixed estimates were always less than the range estimates, and the second being that the forecasted inflation rate produced cash flows that were significantly different than the arbitrary rate selected, showing that subjective project analysis procedures could lead to improper decision making.

REFERENCES

AbouRizk, S.M., Babey, G.M., and Karumanasseri, G. (2002) "Estimating Capital Projects: An Empirical Study of Accuracy Levels for Municipal Government Projects." *Canadian Journal of Civil Engineering* 29 (5): 653-661.

AbouRizk, S.M., and Hajjar, D. (1998). "A Framework for Applying Simulation in Construction." *Canadian Journal of Civil Engineering*. 25(3), 604-617.

AbouRizk, S.M., Halpin, D.W., and Lutz, J.D. (1992). State of the Art in Construction Simulation. *Proceedings of the 1992 Winter Simulation Conference*, Arlington, V., 1271-1277.

AbouRizk, S.M., Shi, J., McCabe, B., and Hajjar, D. (1995). "Automating the Process of Building Simulation Models." *Proceedings of the 1995 Winter Simulation Conference*, Piscataway, NJ., 1032-1038.

Carr, R.I. (1979). "Simulation of Construction Project Duration." *Journal of Construction Engineering and Management*, 105(2), 117-128.

Dabbas, M., and Halpin, D.W. (1982). "Integrated Project and Process Management." *Journal of the Construction Division*, 109(1), 361-373.

Gaynor, P.E. and Kirkpatrick, R.C. (1994), Introduction to Time Series Modeling and Forecasting in Business and Economics, McGraw-Hill, Inc.

Hajjar, D., and AbouRizk, S. (1999). "Simphony: An Environment for Building Special Purpose Construction Simulation Tools." *Proceedings of the 1999 Winter Simulation Conference*, Phoenix, AZ., 998-1006.

Liu, L.Y. and Ioannou, P.G. (1992). Graphical Object-Oriented Simulation System for Construction Process Modeling. *Proceedings of the Eighth Conference on Computing in Civil Engineering*, Dallas, TX., 1139-1146.

Lu, Y.C., Wu, S., Chen, D.H., and Lin, Y.Y. (2000). "BOT Projects in Taiwan: Financial Modeling Risk, Term Structure of Net Cash Flows, and Project at Risk Analysis." *The Journal of Project Finance*, 5(4), 53-63.

Lutz, J.D. (1990). Planning of Linear Construction Using Simulation and Line Balance. Ph.D. Dissertation, School of Civil Engineering, Purdue University, W. Lafayette, IN.

Odeh, A.M., Tommelein, I.D., and Carr, R.I. (1992). Knowledge-Based Simulation of Construction Plans. *Proceeding of the Eighth Conference on Computing in Civil Engineering*, Dallas, TX., 1042-1049.

Ruwanpura, J.Y., Powers, G., Dolhan, G., and Chu, M. (2002). Simulation Based Project Selection Decision Analysis Tool. *Proceedings of the 2002 Winter Simulation Conference*, Not yet published.

Ye, S., and Tiong, R.L.K. (2000). "NPV-at-Risk Method in Infrastructure Project Investment Evaluation." *Journal of Construction Engineering and Management*, ASCE, 126(3), 227-233.

Table 2: Simulation results

Work Package	5 yr. Fixed Estimate Cost (No Inflation)	5 yr. Fixed Estimate + 3% Inflation	5 yr. R.E. (No Inflation) (Mean)	5 yr. R.E. + Forecasted Inflation (Mean)	5 yr. R.E. + 3% Inflation (Mean)	15 yr. R.E. + Forecasted Inflation (Mean)	15 yr. R.E. + 3% Inflation (Mean)
Land Acquisition	$ 8,533,680.00	$ 8,728,126.97	$ 8,533,680.00	$ 8,641,018.69	$ 8,728,126.97	$ 10,429,176.00	$ 11,429,684.30
Utility Relocations	$ 2,325.60	$ 2,454.24	$ 2,325.60	$ 2,407.67	$ 2,454.24	$ 2,906.02	$ 3,213.89
Detour Lanes	$ 819,840.00	$ 865,189.57	$ 896,359.16	$ 904,812.98	$ 945,389.56	$ 1,122,916.99	$ 1,240,402.05
New Roadway	$ 5,831,448.00	$ 6,154,015.39	$ 6,215,068.16	$ 6,412,024.31	$ 6,565,788.42	$ 7,787,411.98	$ 8,596,883.59
Storm Drainage	$ 3,612,039.19	$ 3,806,610.06	$ 3,697,465.00	$ 3,823,845.11	$ 3,891,688.72	$ 4,610,990.48	$ 5,097,794.14
Fill Placement	$ 2,887,536.00	$ 3,096,609.21	$ 4,277,634.77	$ 5,391,153.82	$ 5,425,960.53	$ 6,606,391.97	$ 7,028,727.97
CN Structure	$ 3,556,275.00	$ 3,747,797.71	$ 3,374,765.73	$ 3,635,517.26	$ 3,765,093.42	$ 4,355,306.43	$ 4,929,017.02
YHT Structure	$11,201,868.80	$11,935,219.98	$10,913,811.45	$11,705,536.85	$12,062,921.45	$ 14,151,983.99	$ 15,802,506.06
Street Lights/Signals	$ 3,176.40	$ 3,574.16	$ 3,176.40	$ 3,445.75	$ 3,574.15	$ 4,159.40	$ 4,680.45
Paving Interchange	$ 375,162.00	$ 422,635.76	$ 410,578.84	$ 446,252.74	$ 462,682.11	$ 544,406.49	$ 606,484.22
Remove Detour Road	$ 245,280.00	$ 277,464.25	$ 316,581.14	$ 348,410.62	$ 353,769.10	$ 411,859.82	$ 463,236.72
Landscaping	$ 951,215.75	$ 1,022,410.87	$ 955,767.08	$ 1,009,258.42	$ 1,037,879.19	$ 1,206,193.54	$ 1,357,614.03
Traffic Management	$ 240,876.00	$ 262,732.35	$ 240,876.00	$ 255,152.32	$ 262,732.35	$ 307,990.58	$ 344,054.10
Total Project Cost	$38,260,722.74	$40,324,840.54	$39,838,089.33	$42,578,836.54	$43,508,060.22	$ 51,541,693.68	$ 56,904,298.52
Variance	-	-	$ 1,377,553.96	$ 1,193,838.58	$ 1,191,478.87	$ 1,413,444.80	$ 1,434,936.43