University of Alberta

Modeling Uncertainty in Capital Construction Projects with Lengthy Implementation Time Frames

by

Nathan David Boskers ©

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ABSTRACT

Current techniques for analyzing large capital investment projects with long implementation time frames have two inherent problems. The first is that the rate used to account for the escalation of costs due to inflation is either not used, or inaccurately selected. Second, the estimates of activity durations are fixed as a single value, not accounting for the uncertainty and variability associated with the estimated durations.

To be able to use an accurate inflation rate in the analysis of a project, the Box-Jenkins time-series analysis forecasting technique can be used. To be able to account for the uncertainty and variability in the duration estimates of the project, simulation techniques can be incorporated.

This thesis presents how the forecasted inflation rates and the simulation techniques can be used together to produce a future project cash flow. The cash flow that is produced is more vigorous than the current methods used to estimate cash flows.

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 PROJECT ANALYSIS MODELS

The analysis of a project at the early stages in a project's life is done for various reasons. An organization may have capital readily available to invest, and want to determine which project at hand, if any, should be selected to pursue. This analysis is often referred to as project selection analysis. Other reasons for analyzing projects can be purely investment related reasons. Chen (1998) lists three types of reasons for capital investment.

The first reason is for new profit, which is generally the expansion of current operations or the entering of a new market. The second reason is for business protection, which is investing to maintain capacity of work. And the third reason is out of obligation.

Another reason for analyzing a project at the early stages of its life is to determine optimal procurement strategies to use for carrying out the project's work packages and activities. Whatever the reasons are for capital investment analysis, or project procurement analysis, the analysis done at the early stage of the project is extremely important, because the decisions made based on the analysis done will have large impacts on the outcome of the project. Hence, it is crucial for the organization to use vigorous project analysis techniques.

For the purpose of analyzing projects for selection, Chen suggested the use of the Internal Rate of Return (IRR) method, because it is the most common and understood method in industry. This suggestion of using the IRR method is not supported by all project analysts. Winston (1995) concluded that the most appropriate method for project selection was the use of the Net Present Value (NPV) method. Winston concluded that the NPV method was superior to the IRR method because the IRR method assumes that all funds received during the project can be immediately reinvested at the same interest rate as the IRR. In fact, as the IRR increases, the chance that additional projects are available for reinvestment at that rate decreases. The main reason though that Winston concludes that the NPV method is superior to the IRR method is because the IRR method cannot differentiate between the size differences of the investments.

Ye and Tiong (2000) performed a study on project analysis methods for the purposes of determining the most appropriate analysis method for build-operate-transfer type projects. The research conducted is applicable to other types of projects as well, not only the build-operate-transfer type. Ye and Tiong broke the project analysis methods into three categories: the return methods (i.e. payback period, IRR, NPV), the risk methods (i.e. risk rating systems), and the risk-return methods (i.e. utility theory, decision trees, NPV at discount rate determined by the weighted average cost of capital). Ye and Tiong concluded that the main problem with the return methods were that they assumed the future cash flows required for the calculations were certain. This in fact is not true, as uncertainty increases with time, therefore making it impossible to know the future cash flows with absolute certainty. The problems with the risk rating systems are that they are intended for credit risk, not other forms of investment risk. Numerous problems exist with the risk-return methods. For example, decision tree analysis does not incorporate when the occurrence of the returns take place (time-value of money).

Ye and Tiong developed what they called the NPV-at-risk method. They defined the NPV-at-risk as a particular NPV that is generated from a project at some specific confidence level, that is, the minimum expected NPV with the given confidence level (Ye and Tiong 2000). Ye and Tiong essentially concluded that of the existing project analysis methods, the risk-return method NPV at a discount rate determined by the weighted average cost of capital was the most appropriate method to be used. Using this model as the basis point, Ye and Tiong applied Monte Carlo analysis to the input data (project parameters such as activity costs). By doing this, they were able to produce a NPV distribution curve. Depending on the confidence desired by the analyst, the analyst could determine if the project NPV was above zero or below.

Others have also used this method of project analysis. Wajs et. al. (2000) applied Monte Carlo analysis to project costs for the analysis of a solid waste facility. The optimal solution to this approach was the minimization of risk, which was achieved when the expected NPV was maximized, and the NPV variance and standard deviation for the NPV distribution were minimized. Wajs et. al. used the spreadsheet add-in *Crystal Ball* to perform the analysis.

For the purpose of analyzing construction costs, Cochrane (1992) used Monte Carlo analysis to reduce the risk in uncertainty of estimated construction activity costs. Cochrane used historical data to produce cost ranges, which were then used in the Monte Carlo analysis. Cochrane used the spreadsheet add-in *@Risk* to perform the analysis.

For the purpose of analyzing build-operate-transfer type projects, Lu et. al. (2000) combined the project-at-risk methodology with the NPV methodology. Like Ye and Tiong, Lu et. al. applied the Monte Carlo analysis to the project parameters and produced a NPV distribution as the output. Using the NPV distribution, confidence levels could be applied to the distribution to see if the project NPV was above zero at a desired confidence level.

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 and Lu et. al., 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. However, due to the nature of the NPV-at-risk method requiring forecasted future cash flows, two inherent problems exist in the current research to date. The first problem is in regards to the forecasted future cash flow. The future cash flow is the most important part of any cash flow analysis. The methods developed by the researchers discussed fail to incorporate proper techniques to make the input cash flows as accurate as possible. Second, the research done by the above authors does not properly account for the scheduling of the projects work packages and activities. The researchers apply the Monte Carlo analysis to the costs to quantify uncertainty. This was done, as mentioned earlier, because no future cost is known with absolute certainty. The same argument can be made for the duration of the activities. No future activity duration is known with absolute certainty. The duration is actually quite uncertain, just like the costs. This is a flaw in the current research, because what time the activity occurs in the future will have a major impact on the project total NPV. This is because the NPV calculation is based on the timing and occurrences of future cash flows. The reason that the researchers did not account for the uncertainty in the duration of activities was due to the limitations created by modeling the project costs in spreadsheet type software programs. Although Ruwanpura et. al. did not use a spreadsheet type software program to model the project costs, they just required the user to input the activity duration and time of occurrence for the NPV calculations. In order to correctly input this time, it would have to be known when it would occur and known how long it would occur with absolute certainty, which in reality is not possible.

1.2 FORECASTING CASH FLOWS

Cash flows occur over a period of time. A cash flow may or may not incorporate the escalation of costs due to the inflation of money, hence some definitions need to be established to distinguish the difference between a cash flow that does not incorporate inflation, and one that does. Here, a cash flow in current dollars is one in which the escalation due to inflation is not incorporated, and a cash flow in actual dollars is one in which the escalation due to inflation is incorporated.

According to Smith (1991), the most important part of discounted cash flow analysis is to have a good estimate of the cash flows. Ranasinghe (1996) developed formulas for decision makers to estimate cash flows. The formulas developed begin by using a discrete base cost in current dollars, and discrete cash flows with discrete inflation rates. By using the discrete inflation rate, the analyzer can determine the actual future costs. Although the formulas developed by Ranasinghe are technically sound for estimating the future cash flows, there are problems with the assumptions that were used in developing them. Ranasinghe assumes that the cash flow is known, and that the inflation rate is known. In reality the cash flows, as well as the inflation rate, are quite uncertain, and cannot be assumed to be discrete values. Here, the incorporation of Monte Carlo analysis would prove to enhance Ranasinghe's developed model. In regards to the discrete inflation rate, this value is most often times chosen subjectively by analysts. By subjectively choosing an inflation rate, the input into the model is subject to the analyst's personal biases, which results in the output becoming subjective. As well, by subjectively choosing a constant inflation rate, such things as seasonality, which will effect the project total NPV, are not taken into account.

1.3 COMPUTER SIMULATION IN CONSTRUCTION

Computer simulation can be defined as 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 are ideal tools in 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.

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.

1.4 LIMITATIONS OF CURRENT ANALYTICAL APPROACHES

An inherent problem with the current project analysis methods is that they do not properly incorporate schedule network analysis. This analysis is important because the NPV calculation is greatly effected by the time the activities occur in the lifecycle of the project.

Another problem with the current analytical approaches is that they assume that the duration of the activities are discrete, and known with absolute certainty. This assumption is incorrect, as any kind of knowledge about the future is always uncertain. Again, incorporating uncertainty into the activity duration is important because the duration of an activity will impact the start of a succeeding activity, which will in turn impact the NPV calculation.

The final limitation to the current analytical approaches is that the escalation of costs due to inflation is not properly incorporated into the analysis. Sometimes the inflation of money is not incorporated at all into the analysis, which is obviously not a correct way to incorporate the escalation of costs due to inflation into the analysis. When inflation is incorporated into the analysis, it is incorporated by subjectively selecting a future inflation rate. The subjective selection of the inflation is not an acceptable means of incorporating the escalation of costs due to inflation into the analysis, because it becomes subject to the analysts personal bias. As well, the subjective inflation rate does not incorporate seasonal fluctuations that exist in the value of the actual inflation rate. By subjectively selecting the inflation rate, it stays as a fixed value, when in reality it is dynamic, changing with the seasonal fluctuations in the market. This too affects the NPV calculation.

1.5 RESEARCH CONDUCTED

The objectives of the research conducted were to:

1. Develop a method that properly accounts for the timing of the project's activity occurrences.

2. Develop a method that properly accounts for the inherent uncertainty in the duration of the project's activities.

3. Develop a method that properly accounts for the escalation of costs due to inflation.

To achieve these objectives the following research was conducted:

1. Developed an understanding of forecasting techniques, in particular the Box-Jenkins methodology. This methodology was used as the method for forecasting future inflation rates to be used in the project model analysis (details of this research are discussed in Chapter 3).

2. Integrated project schedule, time of activity occurrence, the uncertainty of activity durations, the uncertainty of activity costs, and the escalation of costs due to inflation into a simulation framework (details of this are discussed in Chapter 2).

3. Using the simulation framework, a SPS tool was developed for the purposes of project analysis (details of this are discussed in Chapter 4).

4. A case study was performed on an actual City of Edmonton infrastructure project to demonstrate the developed SPS tool (details of this are discussed in Chapter 5).

1.6 CONCLUSION

Project analysis is important at the early stages of project planning. Current methods fail to properly account for network analysis; as well they assume future cash flows are known. The research conducted here attempts to account for these downfalls.

CHAPTER 2: PROJECT LIFECYCLE COST ANALYSIS METHODOLOGY

2.1 INTRODUCTION

The analysis of future projects always requires knowledge of future events. The events may be social, political, economical or others. Because the events occur in the future, knowledge with absolute certainty about any event is not possible. Forecasting events is the prediction of what will occur in the future. The forecasting that is done by analysts may be as simple as arbitrarily picking numbers based on subjective personal experience. Analysts may thoroughly analyze current market conditions and other factors and use those results to predict future events. Other analysts may use historical data and assume that history will repeat itself in the future. Whatever the forecasting technique used, and no matter the amount of effort that is put into the forecast, it will always be inherently uncertain.

Forecasting future cash flows is required for the analysis of capital investment projects. This chapter will discuss a methodology that was developed to forecast and analyze future cash flows.

2.2 DEVELOPED PROJECT ANALYSIS METHODOLOGY

As discussed in Chapter 1, the current methods for project analysis have limitations. The first limitation is that they do not account for proper schedule sequencing of a project's activities. The second is that they make the incorrect assumption that a project's activities durations are known with absolute certainty, and have fixed values assigned to them. And finally, they subjectively choose an inflation rate without quantified reasoning behind the choice.

A methodology was developed to be able to better analyze projects by accounting for the limitations that exist in the current methodologies. The developed methodology is summarized in Figure 2:1.

2.2.1 Steps 1 and 2: Break Project into Work Packages and Activities

The first two steps of the developed methodology are similar to creating a project schedule. In the first step, the analyst should break the project into work packages. By breaking the project into work packages, the analyst is defining the major stages or phases of the work that is to be done (phases of a project lifecycle). Most projects have similar phases to their lifecycle, no matter the type of project. In general, a project begins with conceptual planning, and moves on to design, construction, and operation and maintenance. Although other work packages may be defined, these are the main components on a large scale.

Once the work packages have been defined, they should be arranged in such a way as to represent their lifecycle occurrences. This is done by developing a project schedule for the work packages, similar to creating a CPM or PERT schedule. By doing this, a proper network is established so that network analysis can be done on the project.

The second step of the developed methodology is again similar to creating a project schedule. The analyst should break each work package into further work packages, or into activities. The purpose of this step is to allow the analyst to be able to incorporate as much detail into the analysis as desired. An example of this could be a construction work package. The analyst could break this work package into sub-work packages. For example, sub-work packages to the construction work package could be earthwork, foundations, superstructure, and so on. The analyst could then break these sub-work packages into activities. For example, the

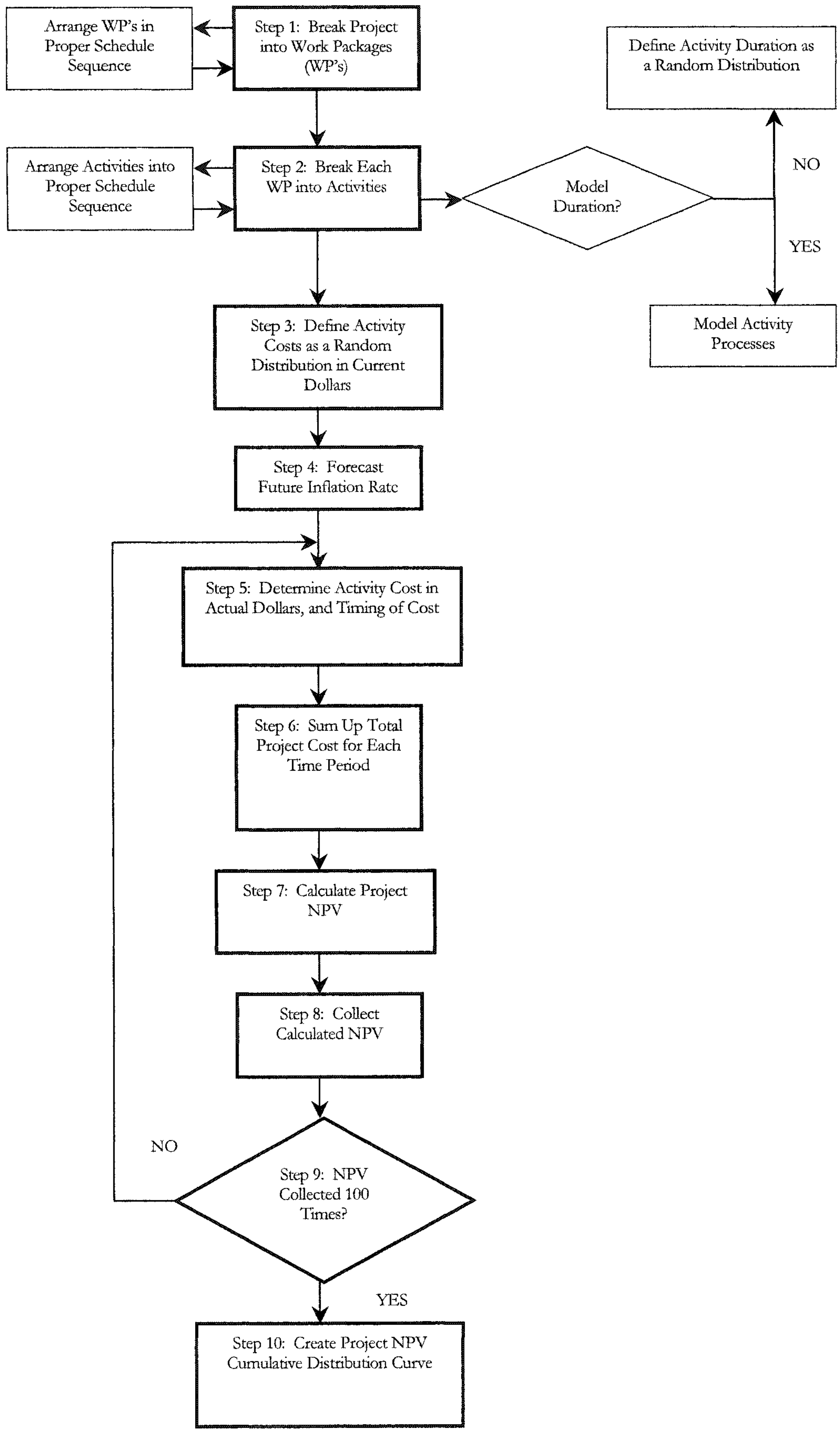

Figure 2:1 - Developed Project Analysis Methodology Flowchart

foundations sub-work package could be broken down into forming, pouring, and finishing activities. This concept is known as hierarchical modeling.

Hierarchical modeling allows the analyst to create a model with as much or as little detail as desired. Figure 2:2 gives an illustration of how hierarchical modeling works. The diagram shown in Figure 2:2 corresponds to the first two steps in Figure 2:1. It should be noted that in hierarchical modeling, there is no limit to the number of levels that can exist. Figure 2:2 just shows three levels, however many more levels could exist if so desired by the analyst.

Again, like the first step, the analyst should then arrange the activities in such a way as to represent their proper sequencing within the work package they belong to. This is done by creating a simple CPM or PERT schedule. By doing this, proper network analysis is incorporated into the overall project analysis.

The final task the analyst needs to do in the second step of the developed methodology, is to decide if the activity's processes should be modeled. The purpose of modeling an activity's processes would be to produce more detailed and accurate output in the analysis. By modeling an activity's processes, the duration of the activity is determined by the finish time of the process, instead of using a user defined duration value. Doing this accounts for the uncertainty that exists in the duration value of future activity times.

If the analyst does not want to model the processes of an activity, a random distribution may be assigned to the duration value. This too takes into account the uncertainty in the activity duration, and is a better way to represent the duration than by just assigning a fixed value.

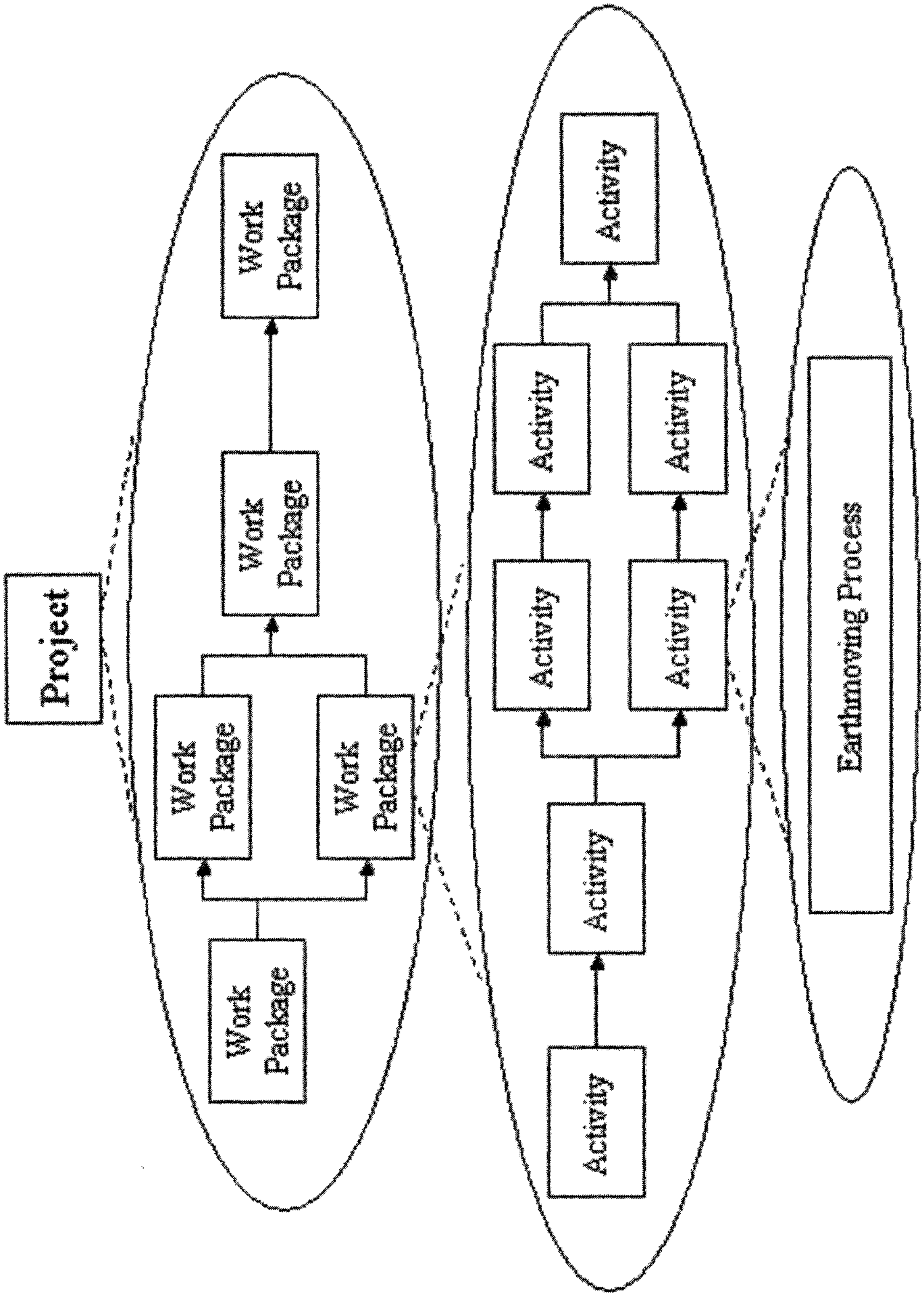

Figure 2:2 - Project Hierarchical Modeling

2.2.2 Step 3: Define Activity Costs

The third step in the developed methodology is to define random distributions for the activity's costs. In step 5, the activity cost will be determined by sampling from the assigned distributions. By doing this, the uncertainty associated with the future unknown costs of the activities are accounted for.

It should be noted at this point that the values used at this step are in current dollars. The escalation of costs due to inflation will be incorporated into the analysis at a later point. These values come from cost estimates performed by expert estimators, and are usually based on historical data, such as productivity rates.

2.2.3 Step 4: Forecast Future Inflation Rate

The fourth step requires the analyst to forecast the future inflation rates of the project. As discussed previously, one of the limitations of the current methodologies is that they assign a subjective value for this rate. In the methodology developed here, this deficiency is accounted for by forecasting the future inflation rate using the Box-Jenkins time-series analysis technique. Using this technique, future inflation rates are forecasted based strictly on statistical principles, and are free from any biases the analyst may have.

The details of forecasting future inflation rates using the Box-Jenkins time-series forecasting technique are described in Chapter 3.

2.2.4 Step 5 and 6: Calculate Time Period Cash Flows

The fifth step is where calculations in the analysis begin. Up to this point, the schedule (or sequencing) of activities has been defined. The cost and duration for each of the activities has also been defined. As well, inflation rates have been forecasted for each future time period.

The purpose of this step is to calculate the cost of each activity in actual dollars. To do this, enhanced versions of Ranasinghe's developed formulas for calculating future cash flows were developed and used.

For construction projects, Ranasinghe determined the total cost of construction (TPC) to be:

$$TPC = base\ cost + EDC + IDC \quad (2.1)$$

where *base cost* is the sum of the project's activity's cost in current dollars, EDC is the escalation during construction costs due to inflation, and IDC is the interest during construction on money financed. Although this formula is stated to be during construction, the same formula can be applied to a project's overall lifecycle, taking into account the design phases, and operation and maintenance periods if so desired. In this case the *base cost*, EDC, and IDC would not all be costs, rather some would be costs, while others would be revenue.

Ranasinghe determined the EDC to be:

$$EDC = \sum_{j=0}^{n-1} A_j \prod_{k=0}^{j} (1 + \theta_k^d) - \sum_{j=0}^{n-1} A_j \quad (2.2)$$

where n is number of cash flows, j is the number of activities, A is the cash flow in current dollars, k is a time period, and θ_k^d is the discrete inflation rate for the kth time period. This formula follows basic engineering economic principles of simply discounting future cash flows into current dollars. However, at the conceptual stage of project, when project analysts are analyzing a project to determine its feasibility, many of the input parameters required for this equation are not known with certainty. In reality, the activity duration, interest rate, and base cost are all uncertain because they will occur in the future, and cannot be represented by fixed input parameters as shown above. Therefore, a more realistic method of representing the EDC would be to incorporate uncertainty into the input parameters.

Equation (2.1) and (2.2) can be considered to be discrete, which assumes that all the input parameters are known with absolute certainty. As explained previously, this is not realistic. Monte Carlo analysis techniques can be incorporated into the input parameters to make equations (2.1) and (2.2) more accurate, resulting in the following stochastic equations:

$$base\ cost = \sum_{j=0}^{n-1} Sample(\mu_{Aj}, \pm\sigma_{Aj}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

$$EDC = \sum_{j=0}^{n-1} Sample(\mu_{Aj}, \pm\sigma_{Aj}) \prod_{k=0}^{j} (1 + Sample(\mu_{\theta_k}, \pm\sigma_{\theta_k})) - \sum_{j=0}^{n-1} Sample(\mu_{Aj}, \pm\sigma_{Aj}) \ldots\ldots\ldots (2.4)$$

$$TPC = base\ cost + EDC + IDC \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

where n is the number of cash flows, j is the number of activities, A is the cash flow in current dollars, k is a time period, θ_k is the inflation rate for the kth time period, μ is the mean value of a normal distribution, and σ is the standard deviation parameter of a normal distribution. Using Monte Carlo analysis, the current cash flow A value is determined from a random sample taken from the normal distribution, and the inflation rate θ_k value is the value that was determined using the Box-Jenkins forecasting technique in step 4. It should be noted that in the above equations a normal distribution is used for sake of explanation. Other types of distributions could be used to represent the input parameters if so desired.

Equation (2.3) represents the costs that were defined in current dollars in step 3. The combination of those costs, and the ones calculated using equations (2.4) and (2.5) creates the actual project cost.

For the purposes of project analysis, which will be described in the later steps, the timing of the actual costs needs to be determined. This is done by performing network analysis on the defined work packages and activities. Here, the durations of the activities are determined by randomly sampling the value, or by modeling the activity's processes, and then the start and finish times of each activity is determined. The start and finish time of each activity is then used to break the actual costs of the activity into parts, corresponding to the time period that the activity part falls in. This is done so that parts of all the project's activity costs can be summed up for each time period. Figure 2:3 shows an illustration of an example project's activities and their relationships to the pre-defined project time periods.

Step 6 then, is the summing up of all the expenses and revenues of the project in actual dollars for each time period. The purpose of summing up the project expenses and revenues for each time period is so cash flow analysis can be performed on the project, which is the project analysis technique. See Figure 2:3 for an illustration of how the activities costs are summed up for each time period.

2.2.5 Step 7 and 8: Calculate and Collect the Project NPV

Step 7 is where the actual analysis of the project takes place. The analysis done on the project is the traditional discounted cash flow analysis, which has been used for a long time to analyze projects.

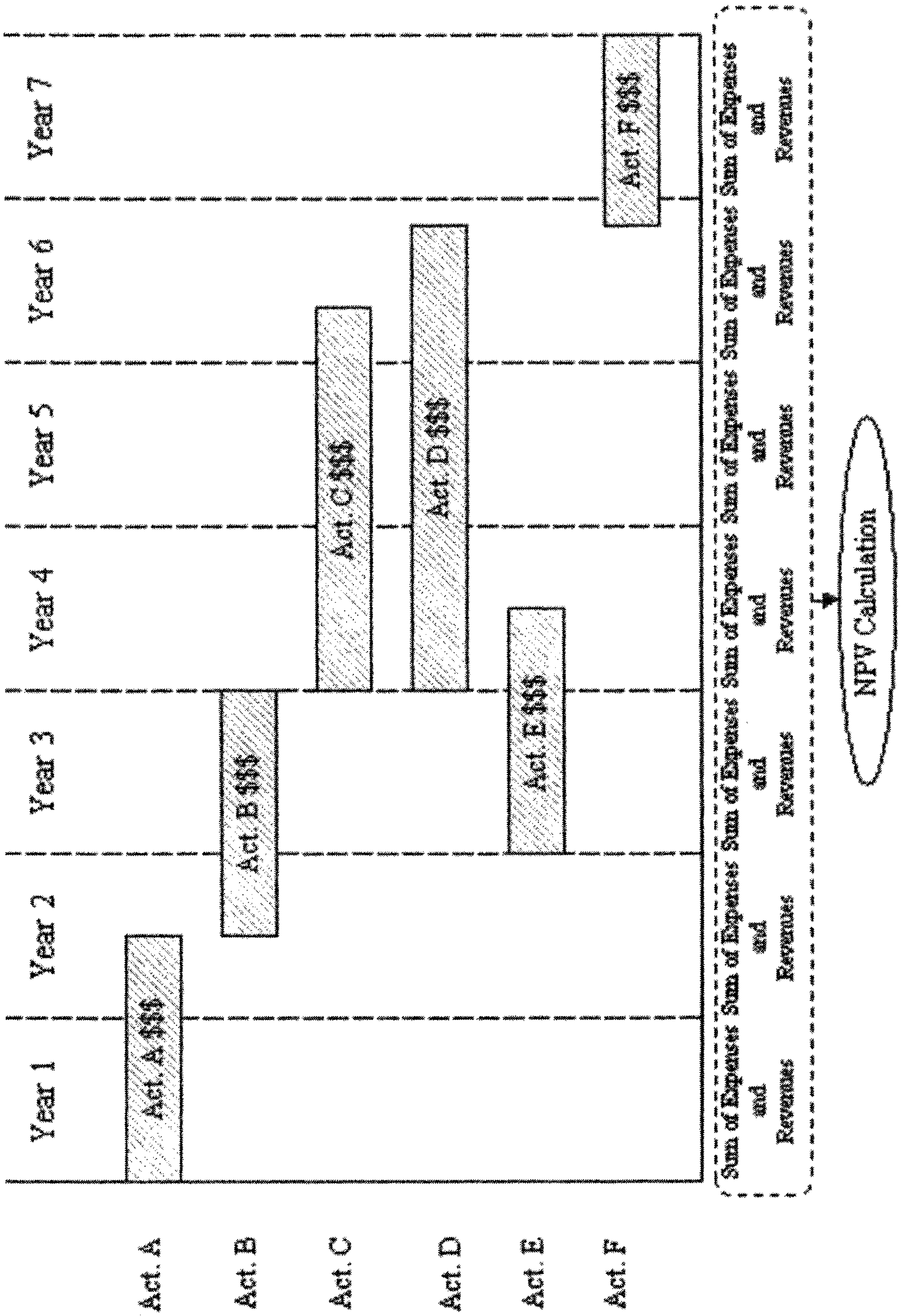

Figure 2:3 - Bar Chart Schedule with Cash Flows

The term project cash flow is the amount of money in a given time period after a project's revenues, expenses, and taxes have been summed. This dollar amount may be zero, positive, or negative. Using cash flow analysis is important when such things as project financing costs are affected by interest rates, and project costs and revenues are affected by inflation rates. Both interest and inflation rates affect the overall total project cash flow. As well, the value of an asset is the extent that it may be expected to generate cash in the future. This value cannot be determined unless cash flow analysis is used, by estimating the future cash and discounting it to the present (Smith 1991).

Discounting cash flows is done by applying a discount rate to the future cash flows in order to bring them back to the present value. When this is done for all the cash flows, they can then be summed up to produce the net present value (NPV). By doing this, a multiple amount of projects can be analyzed and all brought back to the same time to make equal comparisons of all the NPV's. The NPV can be calculated by the following formula:

$$NPV = \sum_{t=0}^{t=n} A_t(1+i)^{-t} \qquad (2.6)$$

where A_t is the project cash flow for period t, and i is the discount factor.

The concept of discounted cash flow analysis is quite simple, yet the output can be quite erroneous if good practice is not used. Smith (1991) outlines a number of important practices when using discounted cash flow analysis. The first recommendation is to create good estimates of future cash flows. Although this seems obvious, the more accurate the cash flow is, the better the output will be. The next recommendation is to work in actual as spent dollar values. This means that the inflation effect on money should be incorporated into the analysis.

This was incorporated into the developed methodology in step 5. The reason actual dollars should be used is because of project financing. Future money being borrowed is not in today's dollars, but in the dollars at the time the money is borrowed. Another recommendation is to choose an appropriate discount rate. Choosing a discount rate is not trivial, and should be based on current market conditions, as this is what dictates the return on investments in the capital market.

Step 7 then is the calculation of the NPV on all of the project's summed up expenses and revenues for each time period. Figure 2:3 shows which values are used in the NPV calculation.

Once the NPV is calculated, the value is collected, or stored in some place, which is step 8. It is here where the concept of Monte Carlo analysis is incorporated into the developed methodology. Steps 5 through 8 are repeated many times, so that a large number of NPV's can be collected. Figure 2:1 shows the question 'NPV Collected 100 Times?' being asked. This was used for illustrative purposes, to show that the NPV needs to be collected many times. This collection of NPV's is what is used in the final step of the methodology.

2.2.6 Step 9: Perform Statistical Analysis on Collect Data

Step 9 of the developed methodology requires the analyst to perform statistical calculations on the collected data. The statistics to be calculated on the data is the mean, minimum, maximum, and variance. As well, a cumulative distribution curve (CDF) of the collected data is created.

The purpose of calculating these statistics is to give the analyst information needed to analyze the project. The most important is the CDF created. By viewing the CDF of the data, the analyst can see the associated levels of confidence versus the NPV's for the project. Ye and

Tiong (2000) used this concept when developing the NPV-at-risk methodology. The basic rule to this methodology is that if the NPV at a desired level of confidence is greater than zero, then the project is worth investing in, and if it is less than zero, then it is not worth investing.

The analyst may wish not to use a discount rate in the analysis. The output of the collected data would just be the total project cost in actual dollars. This is important if the analyst is analyzing a project that will not generate any revenue, but rather will just be an expense, as in the case of many public works projects. The analyst would be able to use the CDF and determine the cost of the project at any level of confidence, with the 100% level of confidence being the maximum value calculated, and the 0% level of confidence being the minimum value calculated.

2.3 DEVELOPED SPECIAL PURPOSE SIMULATION TOOL

The developed methodology described above is setup in such a way so that it can be incorporated into a computer simulation model. The purpose of developing the methodology in such a manner was so a computer could be used, which would reduce the possibility of calculation errors, as well as speed up the calculation purposes. Performing the above methodology without the aid of a computer would be tedious and take up enormous amounts of time. As well, the simulation environment Simphony was used to develop a special purpose simulation (SPS) tool. The steps that incorporate schedule network analysis, and activity duration process modeling could not be met if a simple spreadsheet software program was used. Here is where much of the current methodologies failed, partly due to the lack of an advanced simulation environment in which to develop the models.

The developed SPS tool will be described in detail in Chapter 4.

2.4 CONCLUSION

A methodology for analyzing capital investment projects was developed for the purposes of addressing the current limitations that exist in the current analytical methods. The developed methodology was detailed in 9 steps. The 9 steps were developed in such a way so that a computer simulation tool could be used. A SPS tool was developed for modeling purposes, and is discussed in detail in Chapter 4.

CHAPTER 3: USING THE BOX-JENKINS FORECASTING METHODOLGY FOR FORECASTING PROJECT LIFECYCLE COSTS

3.1 INTRODUCTION

Forecasting is a term used to predict the future. Analysts can use forecasting techniques to make their knowledge of the future more certain, so they can make planning decisions with a higher degree of confidence, which will ultimately increase the chances of a successful project. A common form of forecasting is to use historical data to predict future conditions. Obviously the underlying assumption here is that history will repeat itself. This assumption is not totally true, as all actual projects are undertaken in the real world, which is dynamic, and often times quite random in the events that occur. The attack on the World Trade Centers on September 11, 2001 is a good example of events that could not be predicted by analysts, yet had large impacts on such things as the economy. With that said, historical information can be an excellent source of learning about how systems operate, and how they will most likely continue to operate. An example of this is the weather in the city of Edmonton. The city of Edmonton in northern Alberta tends to be fairly warm in the summer, and quite cold in the winter. It could be said, or rather forecasted in rough terms, that in six months it is going to be quite cold, if it is currently July. It could also be said that the power consumption in Edmonton due to heaters is much less in the summer than it is in the winter, and it can be said with a large degree of certainty that it will continue to be this way in the future. It can be seen then, that although we do live in a random type of real world setting, forecasting using historical information can prove to be an excellent way for planners to make accurate decisions about the future. It should be noted that forecasting is always an estimate of future conditions, and obviously can never be 100% accurate. Often historical data is the only resource available to aid in the task of forecasting the future conditions.

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 forecasting techniques, cash flow analysis can be done more objectively, which will result in the ability to make more informed planning decisions. The purpose of this chapter is to show a method that forecasts future time-series, such as inflation rates, in an objective manner so that they can be used as input parameters for the cash flow forecasting equations developed in step 5, of the methodology discussed in Chapter 2.

3.2 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 (CPI's) 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.

3.2.1 Stationary Time-Series Analysis and Forecasting

According to Mabert (1975), three conditions define a stationary time-series, and are as follows: 1) the observations (historical data), z_t, are taken at equally spaced intervals in time, 2) the process has a constant mean, μ, and 3) the forecast error, a_t, are assumed to be independently distributed random variables with a zero mean and have a constant variance, σ^2, which is the average of the squared deviations from the mean.

Two existing models, and then the combination of those models will be reviewed as methods to analyze stationary time-series models. The first model is the Autoregressive (AR) model, the second model is the Moving Average (MA) model, and the third is the Autoregressive Moving Average (ARMA) model.

3.2.1.1 Autoregressive Models

The autoregressive model is based on regression analysis. In this model the current value is expressed as a linear combination of previous values of the time-series that explain the current value, and a forecast error (unexplained portion), a_t. The AR model equation can be written as follows:

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_p Y_{t-p} + a_t \quad \ldots(3.1)$$

where Y_t is the deviation from the mean ($Y_t = z_t - \mu$), and ϕ_p is the weighted coefficient for the pth previous period. The AR model notation is AR(p).

In this model the current deviation, Y_t, is dependent on the previous independent variables (i.e. Y_{t-1}, Y_{t-2},... ,Y_p). For example, if a model were determined to be of the first order (p=1), then the current value would be determined from $Y_t = \phi_1 Y_{t-1} + a_t$. If an analyst wanted to use the AR(1) model to forecast, the first step would be to determine all previous deviations from the mean, i.e. Y_{t-1}. If the previous deviations from the mean were plotted against the current deviation from the mean, Y_t, a relationship could be expressed as a regression of the two variables, i.e. $\hat{Y}_t = \phi_1 Y_{t-1} + a_t$. It can be seen that the AR(1) model equation is of the form $Y=ax + b$ formula, where a is the slope of the line and b is the y-intercept. The solution to the equation, obtained either directly from the plot, or from other regression analysis such as least squares, would give an estimate of the slope, $\hat{\phi}_1$, and the intercept value, a_t. Once these values are known, they can be put back into the $\hat{Y}_t = \phi_1 Y_{t-1} + a_t$ equation to forecast the future deviations. Since the mean of the stationary time-series is already known, converting the forecasted deviations to future data points, z_t, is simply, $\hat{z}_t = \hat{Y}_t + \mu$.

3.2.1.2 *Moving Average Model*

The second model to analyze stationary time-series is called the Moving Average (MA) model. This model assumes that the current value of the time-series (period t) can be expressed as a linear combination of the previous errors. The MA model equation can be written as follows:

$$Y_t = a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} - \ldots - \theta_q a_{t-q} \quad (3.2)$$

where Y_t is the deviation from the mean ($Y_t = z_t - \mu$), a_t is the forecast error, and θ_q is the weighted coefficient for the qth previous period. The MA model is noted as MA(q). According to Mabert (1975), this model implies that we can gain valuable information for future predictions by considering the weighted sum of the previous forecast errors.

To illustrate the use of the MA model, say an analyst wanted to use an MA(1) model for forecasting. This means that the current data point is based only on the previous period's forecast error. The first step would be to determine the previous deviations from the mean, i.e. Y_{t-1}. Next, for simplicity purposes, the analyst could assume that the forecast error a_t is zero, as that is a condition of stationarity of the time-series, creating a forecasting equation of the form $\hat{Y}_t = \theta_1 a_{t-1}$, where $a_{t-1} = Y_{t-1} - \hat{Y}_{t-1}$. This equation then could then be used for the purposes of forecasting the current data point.

3.2.1.3 *Notational Convention*

Before proceeding to the final analytical model for stationary time-series, some notational convention should be introduced to simplify the formulas. Note that both the AR and MA models involve the use of correlation between the current data point and previous data points in the time-series. Depending on the order of the AR or MA model, the correlation can be with the first previous point, or with many previous points in the time-series. This phenomenon is known as back shifting. To simplify the AR and MA equations to incorporate the amount of back shifting, a back shift operator, B^m, is introduced. The back shift operator controls the extent that previous data in the time-series is used. The back shift operator can be defined for the AR model as follows:

$$(B^m)Y_t = Y_{t-m} \quad \text{(3.3)}$$

and for the MA model as follows:

$$(B^m)a_t = a_{t-m} \quad \text{(3.4)}$$

Note that the back shift operator is subject to the conventional mathematical operation laws, making its use easy to work with. Now, substituting equations (3.3) and (3.4) into equations (3.1) and (3.2), the AR and MA forecasting models can be re-written as follows:

$$Y_t = (\phi_1 B^1 + \phi_2 B^2 + \ldots + \phi_p B^p)Y_t + a_t \ldots\ldots (3.5)$$

$$Y_t = (1 - \theta_1 B^1 - \theta_2 B^2 - \ldots - \theta_q B^q)a_t \ldots\ldots (3.6)$$

3.2.1.4 Mixed Autoregressive – Moving Average Model

The final analytical technique that will be discussed is the combination of the previously discussed AR and MA models. This model is called the Mixed Autoregressive – Moving Average model (ARMA). Mabert (1975) notes that for many series encountered in practice, the inclusion of both autoregressive and moving average terms in a model results in fewer parameters than would be necessary for a satisfactory model of pure AR or MA forms. The result then of the ARMA model, is one that is more efficient than a pure AR or MA model. The ARMA model can be defined as follows:

$$\phi_p(B)Y_t = \theta_q(B)a_t \ldots\ldots (3.7)$$

where $\phi_p(B)$ and $\theta_q(B)$ are polynomials of order *p* and *q*, and are defined as follows:

$$\phi_p(B) = 1 - \phi_1 B^1 - \phi_2 B^2 - \ldots - \phi_p B^p \ldots\ldots (3.8)$$

and

$$\theta_q(B) = 1 - \theta_1 B^1 - \theta_2 B^2 - \ldots - \theta_q B^q \ldots\ldots (3.9)$$

The ARMA model can be expressed as ARMA(*p*,*q*).

As an example of how this model could be used, lets assume an ARMA(1,1) model will be used for the forecast of a stationary series. Equation (3.7) can then be re-written and simplified as follows:

$$\phi_1(B)Y_t = \theta_1(B)a_t \quad (3.10)$$

$$(1-\phi_1 B^1)Y_t = (1-\theta_1 B^1)a_t \quad (3.11)$$

$$Y_t - \phi_1 Y_{t-1} = a_t - \theta_1 a_{t-1} \quad (3.12)$$

$$Y_t = \phi_1 Y_{t-1} + a_t - \theta_1 a_{t-1} \quad (3.13)$$

It can be seen here that the current data point is a function of both autoregression and the moving average.

3.2.1.5 Order Identification of ARMA Models

Thus far, the models discussed have some degree of back shifting used to correlate the current point with previous data points. The examples given for the AR, MA, and ARMA models were only of the order 1. Rarely is an order of 1 satisfactory to the time-series being analyzed. The identification of the model, or the determination of the order of the model, is important in accurately analyzing the time-series.

To identify the order of an AR, MA, or ARMA model, the plot of the Sample Autocorrelation's (SAC), which is called a correlogram, and the plot of the Sample Partial Autocorrelation's (SPAC) are used. Some unique properties of the two plots are used to determine the model's order.

The SAC measures the relationship between data in a time-series, and the SAC function (SACF) describes the nature of the relationship between interdependent observations in a time-series (Mabert 1975). The SAC, or correlation (r_k), is defined as the following:

$$r_k = \frac{\sum_{t=1}^{n-k}(Y_t - \overline{Y})(Y_{t+k} - \overline{Y})}{\sum_{t=1}^{n}(Y_t - \overline{Y})^2} \quad \text{.........(3.14)}$$

where $k=0,1,\ldots K$ and is the lag number of the series, n is the number of observations, Y_t the current deviation from the mean, and $\overline{Y}$ the average series deviation from the mean.

The SPAC measures the strength of the relationship between time periods in a series (Mabert 1975). The SPAC (A_{kk}) is defined as the following:

$$A_{kk} = \begin{cases} r_1 & k = 1 \\ \dfrac{r_k - \sum_{j=1}^{k-1} A_{k-1,j} * r_{k-j}}{1 - \sum_{j=1}^{k-1} A_{k-1,j} * r_j} & k = 2, 3, \ldots, K \end{cases} \quad \text{.........(3.15)}$$

where $A_{kj} = A_{k-1,j} - A_{kk}A_{k-1,k-j}$ for $j=1,2,\ldots,k-1$.

To determine the order of the AR, MA, and ARMA models, the analyst must plot the calculated SAC and SPAC values against the lag k. The shape of these plots helps determine the appropriate order of the models. Table 3:1 is a summary of the unique properties that can be associated with various orders of AR, MA, and ARMA models.

MODEL	SAC FUNCTION	SPAC FUNCTION
MA of order q	Cuts off after lag q (q=1 or 2)	Dies down exponentially and /or sinusoidally
AR of order p	Dies down exponentially and /or sinusoidally	Cuts off after lag p (p=1 or 2)
ARMA of order p,q	Dies down exponentially and/or sinusoidally	Dies down exponentially and /or sinusoidally

Table 3:1 - Behaviour of SACF and SPACF for ARMA Models (Gaynor and Kirkpatrick 1994)

It should be noted that some subjective analyst decisions are required in selecting the most appropriate model. Although guidelines exist, such as those outlined in Table 3:1, no exact rules apply, and the analysts must use their best judgment in selecting the appropriate model.

3.2.2 Non-Stationary Time-Series Analysis

Having discussed stationary time-series analysis, the logical step is to proceed to non-stationary time-series analysis. As mentioned earlier, the attributes of the time-series that project analysts need to analyze in order to make their cash flow forecast more robust are of the non-stationary type. Hence, it is the non-stationary time-series analysis that will be used by project analysts for enhancing cash flow forecasting.

A non-stationary time-series is one where the parameters of the series change over time. The most common form of this is where the mean of the time-series changes over time. These phenomena can be seen in such things as stock market prices. Additional to this could be the presence of seasonal fluctuations in the series, as was noted in the analogy of power consumption due to heaters increasing in the winter months and decreasing in the summer months in the city of Edmonton.

The process of analyzing non-stationary time-series is almost identical to stationary time-series modeling. The first step in non-stationary time-series is to create a stationary time-series out of the non-stationary time-series, and then analyzing the series as if it were a regular stationary ARMA model. In order to create a stationary time-series out of a non-stationary time-series, differencing is performed on the series. Differencing indicates that we create a new series by taking differences between successive periods of the original time-series (Mabert 1975).

Two types of differencing exist, regular differencing, and seasonal differencing. Regular differencing accounts for the changing mean over time, while seasonal differencing accounts for the seasonal fluctuations that repeatedly occur at certain intervals in time. Regular differencing can be defined as follows:

$$Y_t = (1-B)^d z_t \qquad (3.16)$$

and seasonal differencing as follows:

$$Y_t = (1-B^s)^{d1} z_t \qquad (3.17)$$

The combined total differencing would then result from a combination of equations (3.16) and (3.17) as follows:

$$Y_t = (1-B)^d (1-B^s)^{d1} z_t \qquad (3.18)$$

To give an illustration as to how equation (3.18) would be used, say that a given time-series requires regular first differencing (d=1), and seasonal first differencing (d1=1), with an interval spread between fluctuations of twelve (s=12). This would then result in the following substitution and simplification of equation (3.18):

$$Y_t = (1-B)^1(1-B^{12})^1 z_t \quad (3.19)$$

$$Y_t = (1-B^1)(1-B^{12})z_t \quad (3.20)$$

$$Y_t = (1-B^{12} - B^1 + B^{13})z_t \quad (3.21)$$

$$Y_t = z_t - z_{t-1} - z_{t-12} + z_{t-13} \quad (3.22)$$

By applying equation (3.22) to the existing non-stationary time-series, a stationary time-series would be produced, although the number of data points in the newly created stationary series would be reduced by thirteen, as Y_t is a function of the thirteenth previous data point. Any point from 1 through 12 would not have enough previous data points to determine the differenced current data point.

In the above illustration it was assumed that regular first and seasonal first differencing were required to achieve a stationary time-series. This is not always the case. In order to determine the amount of differencing required to achieve a stationary time-series, the analyst must view the plot of the SACF. The SACF for the differenced data will dampen slowly for a non-stationary time-series, but will dampen rapidly for a stationary time-series.

Once an appropriate amount of differencing is chosen, the analyst can use the differenced data the same way as he would have in analyzing a stationary time-series without differencing.

3.2.2.1 Box-Jenkins Model

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:

$$\phi_p(B)Y_t = \theta_q(B)a_t \quad \text{(3.23)}$$

where

$$Y_t = \begin{cases} (1-B)^d(1-B^s)^{d1}z_t & \text{if } d > 0 \text{ and/or } d1 > 0 \\ z_t - \mu & \text{if } d = 0 \text{ and } d1 = 0 \end{cases} \quad \text{(3.24)}$$

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:

$$\phi_p(B)\phi_{p1}(B^s)Y_t = \theta_q(B)\theta_{q1}(B^s)a_t \quad \text{(3.25)}$$

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*).

3.2.3 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 3:1 shows how these steps are carried out.

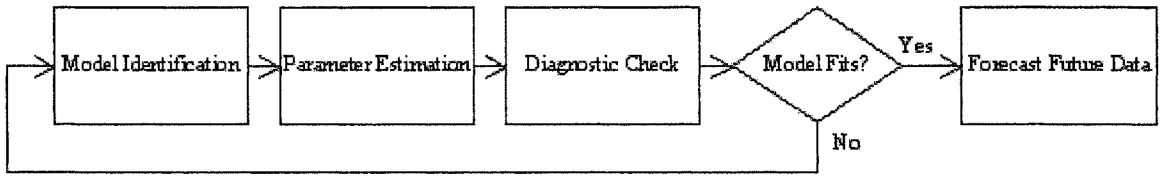

Figure 3:1 - Box-Jenkins Forecasting Methodology

3.2.3.1 *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 SAC's and the plotted SPAC's. 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 SACF's and SPACF's 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, references such as Table 3:1 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.

3.2.3.2 *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 is required for the first iteration. Gaynor and Kirkpatrick (1994) suggest using 0.1 as a good starting value for all ϕ's and θ's being estimated.

3.2.3.3 *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:

$$Q = n\sum_{k=1}^{K} r_k^2(\hat{a}) \quad (3.26)$$

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. Performing the calculation of the SAC's for the residuals is identical to the calculation of the SAC's for differenced data, Y_t, therefore equation (3.14) can be used here as well, only substituting a_t for Y_t. The second step in performing the Chi-Squared test is to determine a Chi-Squared distribution, X^2 (see Appendix A for the Chi-Squared distribution table), 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.

3.2.3.4 *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 (2,0,1,0,0,0) 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:

$$(1 - 0.25B^1 - 0.45B^2)(1 - B)^1 z_t = a_t \ldots\ldots (3.27)$$

$$(1 - 1.25B^1 - 0.2B^2 + 0.45B^3) z_t = a_t \ldots\ldots (3.28)$$

$$z_t = 1.25 z_{t-1} + 0.2 z_{t-2} + 0.45 z_{t-3} + a_t \ldots\ldots (3.29)$$

Converting equation (3.29) 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 (3.29) then becomes:

$$\hat{z}_T(l) = 1.25 z_{T+l-1} + 0.2 z_{T+l-2} + 0.45 z_{T+l-3} + a_{T+l} \ldots\ldots (3.30)$$

Equation (3.30) can then be used to forecast the desired future data from the historical data.

3.3 FORECASTING FUTURE CONSUMER PRICE INDEX FOR THE PURPOSES OF PROJECT CASH FLOW FORECASTING

The purpose of detailing the Box-Jenkins forecasting methodology was to show a methodology for making cash flow forecasting more robust. In the area of project analysis from a construction owner's point of view (analyzing the project from the design phase through to the operation and maintenance phase), current practices account for the escalation of costs due to inflation by subjectively selecting an inflation rate and adjusting the current, or today's dollar, accordingly. Some analysts neglect the escalation of costs due to inflation all together. These two types of analysis are unacceptable, considering that at the early stages of a project, the owner stands to gain or lose substantial amounts of money based on the important decisions made by the analysts. Hence, the tools that are used by the analysts must be the most advanced and detailed as possible, as the owner or investor in the project cannot afford to make erroneous decisions at this stage of the project.

Using the Box-Jenkins forecasting methodology, analysts can forecast future inflation rates, instead of subjectively selecting one, or not using one at all. By forecasting inflation rates, analysts will be taking into account a proper changing mean, as well as incorporating seasonal cycles in the inflation rate. These cycles are important in planning such things as the cost of materials and labour, which are affected by the changing of seasons. Knowing the seasonality of relevant rates can help the analysts decide on ideal times to plan for such things as material and equipment purchases and so forth. This section will detail the steps taken to forecast the Consumer Price Index (CPI) for the Edmonton region. The CPI's measure changes in prices of goods and services individuals and families buy to live (e.g., food, clothing, housing, medicine, recreation, transportation). The indexes measure only prices and do not account for changes in quality (Jones 1982). The CPI is what is most often used to calculate the inflation rate for a particular region.

The historical data for the CPI index was obtained from Statistics Canada (Statistics Canada 2002).

3.3.1 Preliminary Observations

Before proceeding with step 1 of the Box-Jenkins forecasting methodology, some preliminary analysis was done on the data acquired. Figure 3:2 shows a plot of the historical data of the CPI for Edmonton from January 1971 through to April 2002. Upon looking at this plot, it can be seen that the events of September 11, 2001 have caused outlying data points that do not appear to fit the general pattern of the plot. It can be assumed that the events of September

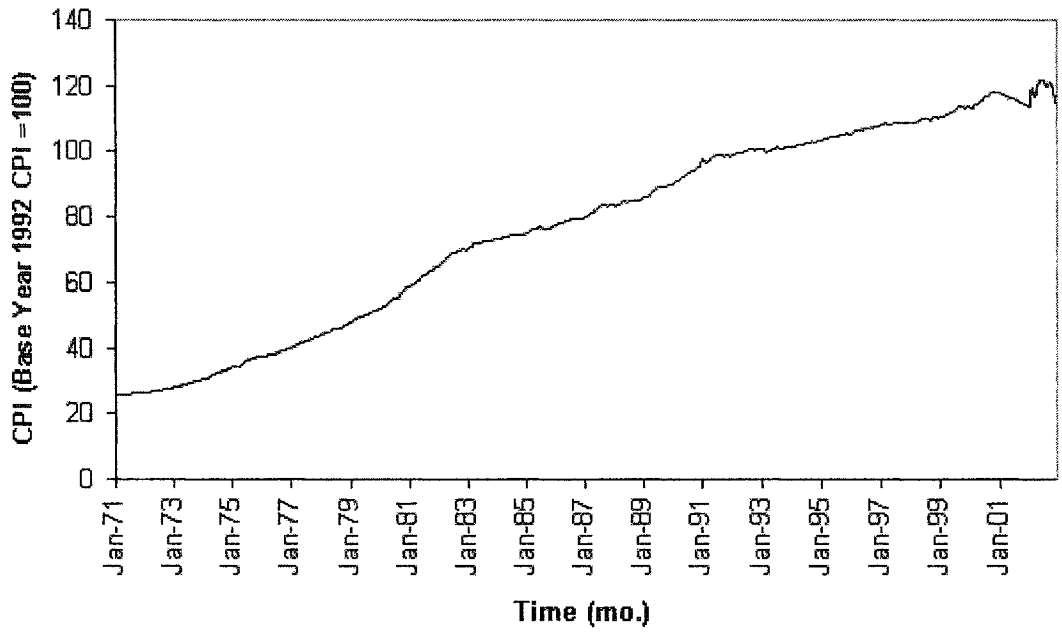

Figure 3:2 - Historical Data Plot for Edmonton Consumer Price Index

11, 2001 are nonrecurring events, and so for the purposes of the analysis at hand, it is best to remove them. This was be done by only analyzing the data prior to the September 11, 2001 date. Another observation made by looking at the plot is that the mean is changing over time, which indicates that this time-series is non-stationary in nature. Because the time-series is non-stationary in nature, differencing was required to obtain a stationary series. Another possible cause of non-stationary results from changes in the magnitude of variation around the mean (Mabert 1975). To account for this, the natural logarithms were taken to the historical data to insure homoscedasticity, which is the state of equal variance throughout the whole time-series population.

Period	Original Series (logged)	No Differencing	Reg. First Differencing	Reg. Second Differencing	Seasonal Differencing
	z_t	$Y_t = z_t - \mu$	$Y_t = (1\text{-}B)z_t$	$Y_t = (1\text{-}2B+B^2)z_t$	$Y_t = (1\text{-}B^{12})z_t$
1	3.23475	-0.93295	No Data	No Data	No Data
2	3.24259	-0.92511	0.00784	No Data	No Data
3	3.23868	-0.92902	-0.00391	-0.01176	No Data
4	3.24259	-0.92511	0.00391	0.00783	No Data
5	3.25037	-0.91733	0.00778	0.00387	No Data
6	3.25037	-0.91733	0.00000	-0.00778	No Data
7	3.25037	-0.91733	0.00000	0.00000	No Data
8	3.25810	-0.90960	0.00772	0.00772	No Data
9	3.26194	-0.90577	0.00384	-0.00388	No Data
10	3.25810	-0.90960	-0.00384	-0.00768	No Data
11	3.26194	-0.90577	0.00384	0.00768	No Data
12	3.26576	-0.90194	0.00382	-0.00001	No Data
13	3.27336	-0.89434	0.00760	0.00378	0.03861
14	3.27336	-0.89434	0.00000	-0.00760	0.03077
15	3.27714	-0.89056	0.00378	0.00378	0.03847
16	3.28091	-0.88679	0.00377	-0.00001	0.03832
17	3.28840	-0.87930	0.00749	0.00372	0.03803
18	3.29213	-0.87557	0.00372	-0.00377	0.04175
19	3.29213	-0.87557	0.00000	-0.00372	0.04175
20	3.29953	-0.86817	0.00741	0.00741	0.04144

Table 3:2 - Differencing CPI Data

Furthermore, to be able to validate the selected model, the model was developed using the logged data from January 1971 through to December 1998, and the data from January 1999 through to December 2000 was used to compare the forecasted results with the actual results.

3.3.2 Step 1: Tentative Model Identification

The first step in analyzing the CPI data was to determine a tentative model from the historical data. This was done by calculating the SAC's for a variety of differencing combinations. In this step, all combinations of d=0 to d=3 and d1=0 to d1=2 were conducted. Once these calculations were made, the SACF's were plotted. Table 3:2 shows the differencing that was done for periods 1 through 20. The differencing computations were done using Microsoft Excel (Microsoft 2000). Special modules were created using Visual Basic for Applications

(VBA) code to aid in the complex calculations (see Appendix B for calculation steps and VBA code).

The SACF for regular first differencing can be seen in Figure 3:3. All the difference, SACF, and SPACF plots can be viewed in Appendix C. Upon observation of the generated plots, it was observed that the plots that tended to dampen the quickest when compared to the others

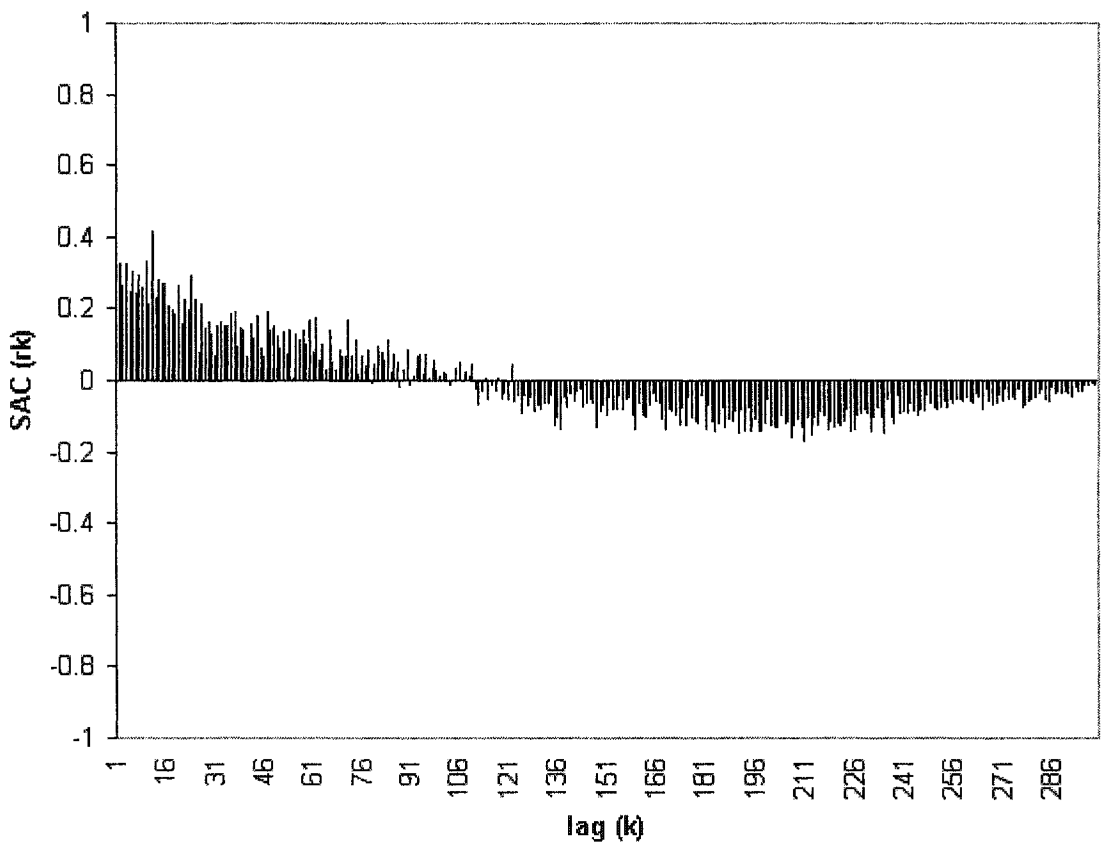

Figure 3:3 - Sample Autocorrelation Function of Regular First Differenced CPI Data

were when d=1 and when d=3. These plots tend to dampen out around 100 lags (*k*). When considering the amount of regular differencing then between d=1 and d=3, the only model that needed to be considered was when d=1. This is because further differencing (when d=3) to an already stationary series would not result in an improved stationary series, since a stationary series is all that was desired to begin with. Further investigation of Figure 3:4 showed that at every twelfth lag, a large SAC value appeared. This indicated that some sort of seasonal differencing was required. When d=1, d1=1 and s=12, the SAC plot showed that the large value at the every twelfth lag was reduced. This then is a more appropriate stationary series than when just regular differencing was performed. Like the argument for the regular differencing, it can be said that when d1=1, stationarity is achieved, hence no more seasonal differencing is needed, as it would not benefit the analysis further. Therefore, at this stage it was determined to use regular first and seasonal first differencing for the CPI data series to achieve a stationary series.

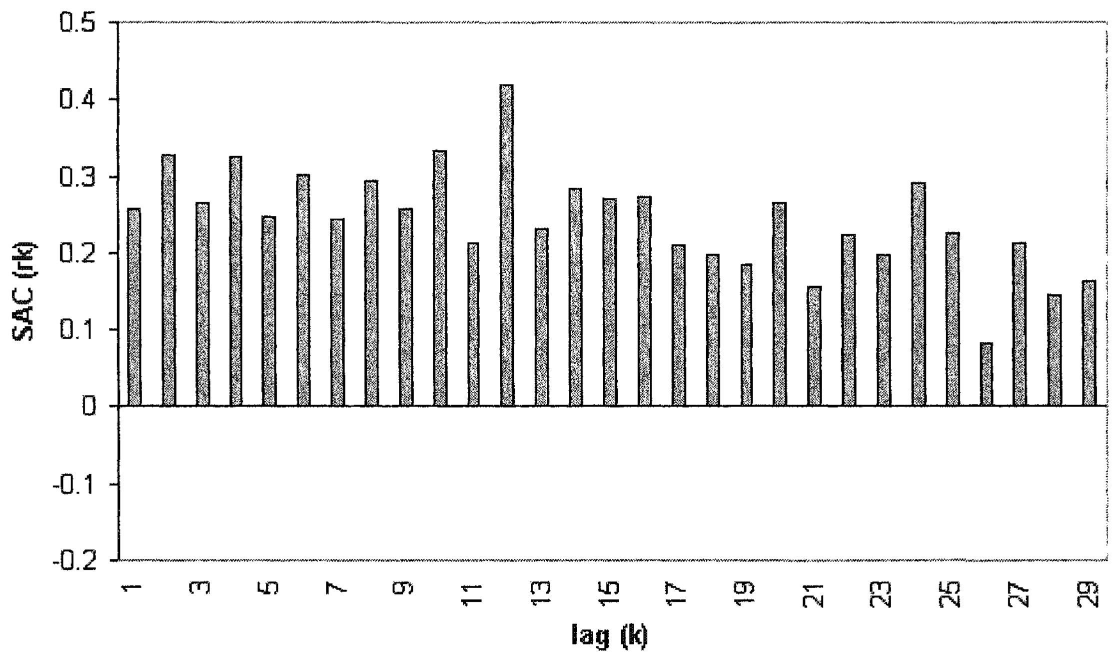

Figure 3:4 - Enlarged SACF of Regular First Differenced CPI Data

Once the required differencing was determined, the AR and MA parameters could be determined from the SACF and the SPACF of the d=1,d1=1 differenced data. Upon observation of Figure 3:3, clearly the shape of the graph was dying down sinusoidally. Table

3:1 indicates that this type of shape is an AR model of an order 2. No other possibilities seemed to be evident, so the tentative model of choice was just the AR(2) model.

The differencing was determined to tentatively be d=1 and d1=1, and the model to be an AR type of order 2, therefore the tentative Box-Jenkins model was written as ARIMA(2,0,1,1,0,0) for the CPI data. This ARIMA model can be described by the following equation:

$$(1-\phi_1 B-\phi_2 B)(1-B)(1-B^{12})z_t = a_t \quad (3.31)$$

3.3.3 Step 2: Parameter Estimation

The second step was to determine the parameters for the tentative ARIMA model. As indicated previously, this step involves many iterations, and is most efficiently done using a computer. The program ASTSA (Shumway and Stoffer 2002) was used to perform this step.

ASTSA is simple to use, the user just uploads a data set from a .dat file, and inputs the ARIMA parameters of the model into the program, and the program estimates the most appropriate estimates by performing an optimization technique. For the CPI problem, ASTSA performed parameter estimation for the parameters $\hat{\phi}_1$ and $\hat{\phi}_2$.

Figure 3:5 shows what the output looks like for the ASTSA program. It can be seen in Figure 3:5 that the estimate for $\hat{\phi}_1$ =0.06687 and the estimate for $\hat{\phi}_2$ =0.02911. The ARIMA model can be written as follows:

$$(1-0.06687B-0.02911B)(1-B)(1-B^{12})z_t = a_t \quad (3.32)$$

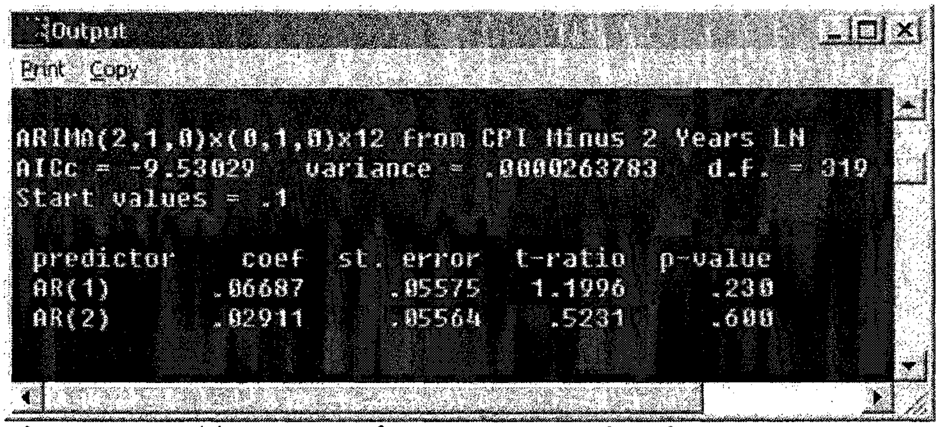

Figure 3:5 - ASTSA Output for Parameter Estimation

3.3.4 Step 3: Diagnostic Checking

The next step was to check the tentative model for appropriate fit. This is done, as mentioned earlier, by checking the residuals, a_t. For this test, the number of residual calculations performed was 20 (*K*). Since *K*=20, the degree of freedom (*K-p-q*) was 20-2-0=18. From the Chi-Squared distribution chart in Appendix A, using a confidence limit of 97.5%, the Chi-Squared distribution X^2 was 31.526. Like the calculation of the SAC's for the data deviations, *Yt*, Microsoft Excel (Microsoft 2000) was used with the aid of VBA modules to perform the calculation (see Appendix B for steps and computer code). Table 3:3 shows how the Chi-Square calculation was done. The calculation of Chi-Squared statistic is as follows:

$$Q = n\sum_{k=1}^{K} r_k^{\,2}(\hat{a}) = 306(0.21709) = 66.429 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.33)$$

It can be seen that $Q > X^2$, which indicates that the tentative model failed the Chi-Squared test. To improve the model, the SACF of the residuals, a_t, was observed.

It can be seen in Figure 3:6 that large SAC values exist at consecutive twelfth lags. This indicates that seasonal parameters could be added to the model to improve it. Therefore, SAR (1) and SMA(1) were added to the model, creating an ARIMA model of ARIMA(2,1,1,1,1,0).

lag (k)	Residual a_t	$r_k(\hat{a})$	$r_k^2(\hat{a})$
1	-0.00043	0.00090	0.00000
2	-0.00051	-0.00023	0.00000
3	0.00375	-0.03167	0.00100
4	-0.00024	0.05280	0.00279
5	-0.00042	0.03667	0.00134
6	0.00354	0.08359	0.00699
7	0.01091	0.01171	0.00014
8	-0.00106	-0.00624	0.00004
9	0.00309	0.06880	0.00473
10	-0.00066	0.09874	0.00975
11	0.00350	-0.02215	0.00049
12	0.00661	-0.38571	0.14877
13	-0.00081	-0.01036	0.00011
14	0.00280	0.15094	0.02278
15	-0.00045	0.05944	0.00353
16	0.00683	0.05418	0.00294
17	0.00579	-0.00481	0.00002
18	0.00215	-0.03064	0.00094
19	-0.00767	0.07552	0.00570
20	0.00347	0.07083	0.00502
			0.21709

$n = 321 - 15 = 306$

Table 3:3 - Residual Test Calculations

This can be described by the following equation:

$$(1-\phi_1 B-\phi_2 B)(1-\phi_{12}B^{12})(1-B)(1-B^{12})z_t=(1-\theta_{12}B^{12})a_t \qquad (3.34)$$

Once again step 2 - parameter estimation, must be performed and then step 3 – diagnostic checking, to see if the improved model is adequate.

ASTSA estimated the parameters as follows:

$\hat{\phi}_1 = 0.0883$ $\hat{\phi}_2 = 0.1637$ $\hat{\phi}_{12} = 0.1139$ $\hat{\theta}_{12} = 0.7832$

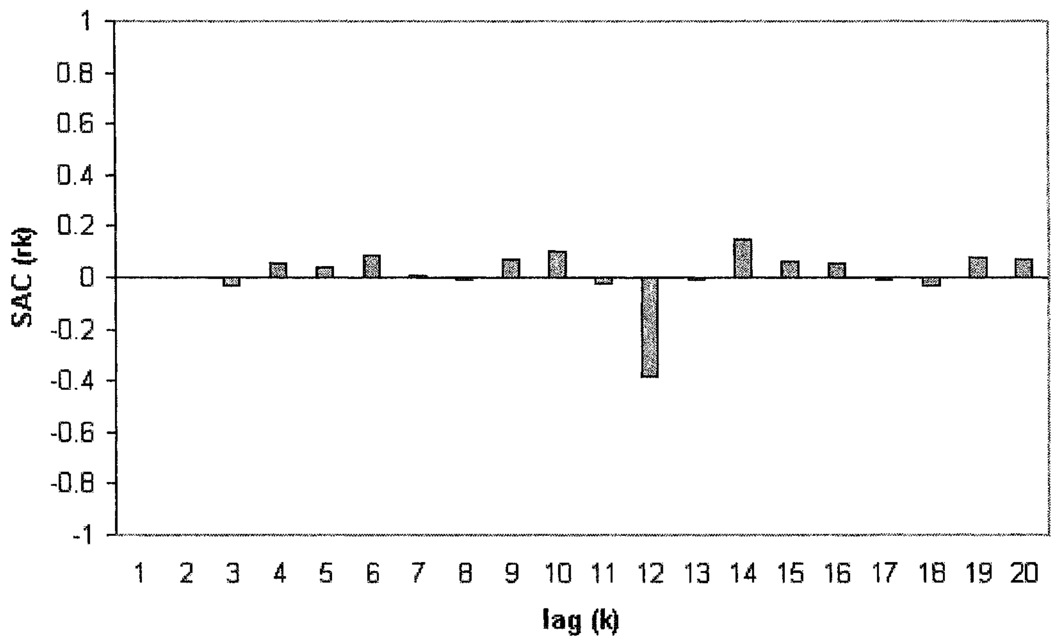

Figure 3:6 - SACF for Tentative Model Residuals (at)

Performing the diagnostic check for the new model resulted in a Chi-Squared distribution, X^2, of 31.562, and a Chi-Squared statistic, Q of 21.698. Now $Q < X^2$, which indicates that the improved model passes the Chi-Squared test.

Therefore, the final model determined to be adequate is ARIMA(2,1,1,1,1,0) model of the form:

$$(1-0.0883B-0.1637B)(1-0.1139B^{12})(1-B)(1-B^{12})z_t=(1-0.7832B^{12})a_t \ldots\ldots\ldots(3.35)$$

3.3.5 Step 4: Forecasting

Once an appropriate model had been determined for the CPI data, a forecasting equation could be determined. This equation was determined by solving for z_t, and substituting $T+l$ for t. This process could be done by hand, but the process is tedious as the number of terms in the equation becomes enormous when the equation is expanded. Therefore for the sake of

t	Forecast	Lower	Upper	CPI
337	4.7070	4.6984	4.7157	110.7195
338	4.7066	4.6938	4.7194	110.6752
339	4.7085	4.6933	4.7236	110.8857
340	4.7114	4.6943	4.7284	111.2077
341	4.7138	4.6950	4.7327	111.4750
342	4.7175	4.6970	4.7380	111.8882
343	4.7199	4.6979	4.7419	112.1570
344	4.7205	4.6971	4.7440	112.2244
345	4.7190	4.6942	4.7438	112.0561
346	4.7206	4.6945	4.7466	112.2356
347	4.7234	4.6962	4.7507	112.5503
348	4.7233	4.6948	4.7517	112.5390
349	4.7272	4.6975	4.7568	112.9788
350	4.7273	4.6960	4.7585	112.9901
351	4.7291	4.6970	4.7612	113.1936
352	4.7318	4.6990	4.7646	113.4997
353	4.7344	4.7008	4.7679	113.7952
354	4.7377	4.7033	4.7720	114.1713
355	4.7405	4.7054	4.7756	114.4914
356	4.7411	4.7052	4.7769	114.5601
357	4.7402	4.7037	4.7768	114.4571
358	4.7413	4.7041	4.7786	114.5831
359	4.7441	4.7062	4.7821	114.9043
360	4.7440	4.7054	4.7827	114.8929

Table 3:4 - Forecast Output for First Twenty Points

time and so errors were not made during the equation expansion, ASTSA was again used to perform the forecasting task. ASTSA only requires the model parameters and will perform the forecasting automatically. Table 3:4 shows the results of the ASTSA forecast output.

Notice that the forecast results are in logged form. To determine the forecasted CPI, the Exp (Value) had to be taken to the forecasted data to get the data back into the original form. Also note that the ASTSA program calculated upper and lower bounds. These bounds represent confidence intervals for the forecasted data. Figure 3:7 shows that the confidence interval

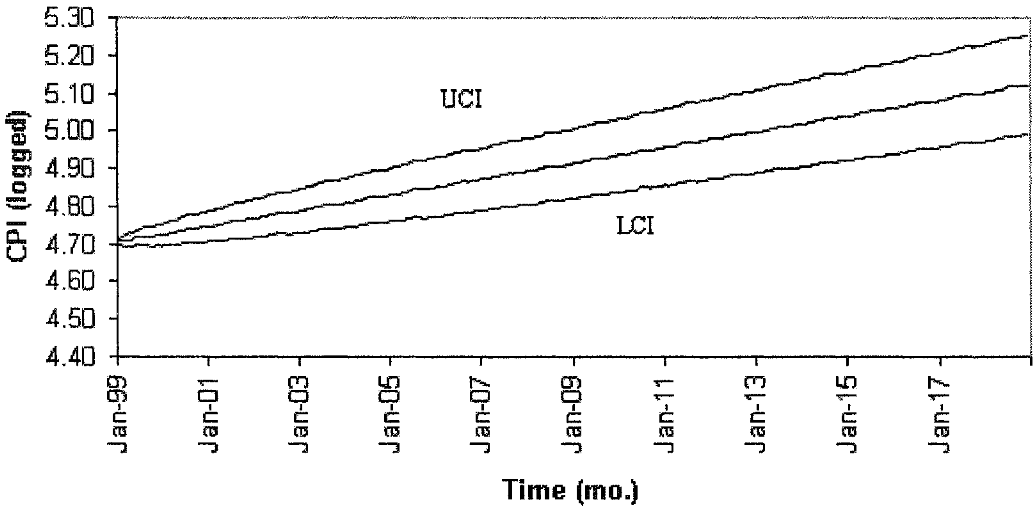

Figure 3:7 - CPI Data Forecast with Confidence Intervals

values increase with respect to the mean over time, which indicates that as time increases the uncertainty with the forecast increases. This makes logical sense, as information about what the state of the economy, politics, environment etc. will decrease as the time in the future increases.

3.3.6 Model Validation

Once the model produced actual future CPI values using the Box-Jenkins methodology, a validation could be done to insure that the model is accurate. Recall that when the preliminary analysis was being done that the model development was done using data for January 1971 through to December 1998, and that the data from January 1999 through to December 2000 was obtained but not used in the model creation. This data can now be used to compare the forecasted data to the actual data. Table 3:5 shows the forecasted CPI data and the actual CPI data for the January 1999 through December 2000 time period. It can be seen from the results of the model that the error in the forecasts are quite small. The error increases quickly into the latter part of the year 2000, as compared to the earlier year and a half. This error most likely results in the sudden and huge boom in the technology industry, sending stock market prices

Date	Forecast CPI	Actual CPI	% Error
Jan-99	110.72	110.50	0.20
Feb-99	110.68	110.50	0.16
Mar-99	110.89	110.70	0.17
Apr-99	111.21	111.00	0.19
May-99	111.47	111.80	0.29
Jun-99	111.89	112.00	0.10
Jul-99	112.16	112.40	0.22
Aug-99	112.22	113.20	0.86
Sep-99	112.06	113.80	1.53
Oct-99	112.24	113.70	1.29
Nov-99	112.55	113.30	0.66
Dec-99	112.54	113.80	1.11
Jan-00	112.98	113.30	0.28
Feb-00	112.99	113.30	0.27
Mar-00	113.19	114.40	1.05
Apr-00	113.50	114.50	0.87
May-00	113.80	115.10	1.13
Jun-00	114.17	115.60	1.24
Jul-00	114.49	116.60	1.81
Aug-00	114.56	116.80	1.92
Sep-00	114.46	117.40	2.51
Oct-00	114.58	117.80	2.73
Nov-00	114.90	118.00	2.62
Dec-00	114.89	118.00	2.63

Table 3:5 - CPI Data Forecast Error

and indices to levels never reached before. This type of sudden increase in market prices could not be forecasted as it is such a rare event. Recall that the forecasting technique is still an estimate of future conditions, and cannot be an exact representation. The purpose in this study is to establish a more accurate and robust method of forecasting future cash flows than those that already exist, which use fixed input values for project costs and make subjective inflation rate value selections.

3.3.7 Input Data for Developed Cash Flow Formula's

Step 5 in the developed methodology discussed in Chapter 2 required the input θ_k. This parameter is the inflation rate for time period k. Using the forecasted CPI values discussed above, the inflation rate for a given time period can easily be calculated using the following formula:

$$\theta_k = \frac{CPI_{current}}{CPI_{previous}} - 1 \quad (3.36)$$

where $CPI_{current}$ is the CPI for current period, and $CPI_{previous}$ was the CPI from the previous period.

3.4 CONCLUSION

Analysts need to use every means possible when performing analysis to aid in decision making for proposed capital investment projects. It was described in this chapter how future inflation rates can be forecasted using the Box-Jenkins forecasting technique. These inflation rates can be used as input parameters for the equations described in step 5 of the developed methodology discussed in Chapter 2.

CHAPTER 4: SPECIAL PURPOSE SIMULATION TOOL FOR PROJECT ANALYSIS

4.1 INTRODUCTION

A special purpose simulation (SPS) tool was developed in the simulation environment Simphony. SPS tools developed in Simphony are called templates. The template created is called the planning template, and is a SPS tool developed 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.
- Can be reused over and over again for a countless number of projects to be analyzed.
- Fully incorporates the developed methodology discussed in Chapter 2.

4.2 STRUCTURE OF TEMPLATE

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

The planning template utilizes some of the functional features built into the Simphony environment. The most important feature that is utilized in the planning template is the statistics and graphs that are automatically produced by Simphony. Using the collected net present value (NPV) data, Simphony performs all the statistical calculations on the data, as well as produces the cumulative distribution function's (CDF's).

4.2.1 Modeling Elements - Input Parameters

The input parameters in the modeling 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 modeling elements and their respective inputs are listed in Table 4:1.

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 modeling elements on lower hierarchical levels are reported to this element and used as input. The *project planner* has the following input parameter (see Table 4:1) for simulation: Discount Rate (%). The discount rate value is what is used in the computation of the overall project's NPV.

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 4:1) 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

Modeling 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	

Table 4:1 - Modeling Elements with Input Variables

(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 4:1) 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.

For a detailed description of all the input parameters and how they are used, see Appendix D: Project Planner User Manual.

4.2.2 Modeling Elements - 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. This statistic represents steps 8 and 9 of the developed methodology that was discussed in Chapter 2. The NPV is collected for each simulation run, and the statistics are calculated on the collected data. The statistics on the collected NPV's is what is used by the analyst to analyze the project. The statistics given then are the project's maximum, minimum, and mean NPV. In addition to this, a CDF is produced. As discussed in Chapter 2, 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.

4.3 CREATING A MODEL

Creating a project specific model in the planning template is quite simple, and requires little simulation knowledge from the user. The Simphony environment allows for the creation of models through the use of a graphical interface.

Using the planning template specifically then, the user only needs to create a project in the form of a CPM network diagram. The model is created is such a way as to model the hierarchical modeling that was discussed in Chapter 2. The graphical user interface allows for the creation of the models to look similar to the diagram shown in Figure 2:2, in Chapter 2. Once the desired model is created, all the user needs to do is enter in the required input values, and run the simulation. As discussed earlier, all the outputs and statistics will be automatically generated.

For a complete description of how to create a simulation model in the project planner template, see Appendix D: Project Planner User Manual.

4.4 CONSTRUCTION OPERATION MODELING FEATURES IN THE DEVELOPED SPS TOOL

As discussed in Chapter 2 in regards to the developed methodology step 2, the analyst has the option of modeling an activity's operation processes, or to enter in a value for the activity's duration. The planning template was developed to incorporate this into the template by allowing the template user to choose between modeling the operations, or to input an activity duration value.

If the template user decides to model the operation, the user can use other templates previously developed for the Simphony simulation environment to do so. An example is given for the purposes of illustrating how this feature works.

4.4.1 Example Description

An earthwork construction operation is used for example purposes to represent the operations of the activity 'Cut and Fill', in the project network diagram. The operation is a basic excavation task, consisting of a scraper loading with fill, traveling loaded to the dump site, dumping the fill, and traveling back to the load site empty. The details of the operation were assumed and are outlined as follows:

Required volume of fill =	500m3
Number of earthmovers =	4ea
Earthmover carrying capacity =	5m3
Loading time =	5min
Travel to dump site time =	20min
Dump time =	3min
Return to cut site time =	17min
Number of push dozers =	2ea

Figure 4:1 shows how the excavation operation model was created in the planning template. It can be seen in the figure that the earthwork operations are part of the 'Cut and Fill' activity, which is part of the 'Earthworks' work package. The graphical image is the user interface that the user would encounter when using the Simphony SPS tool.

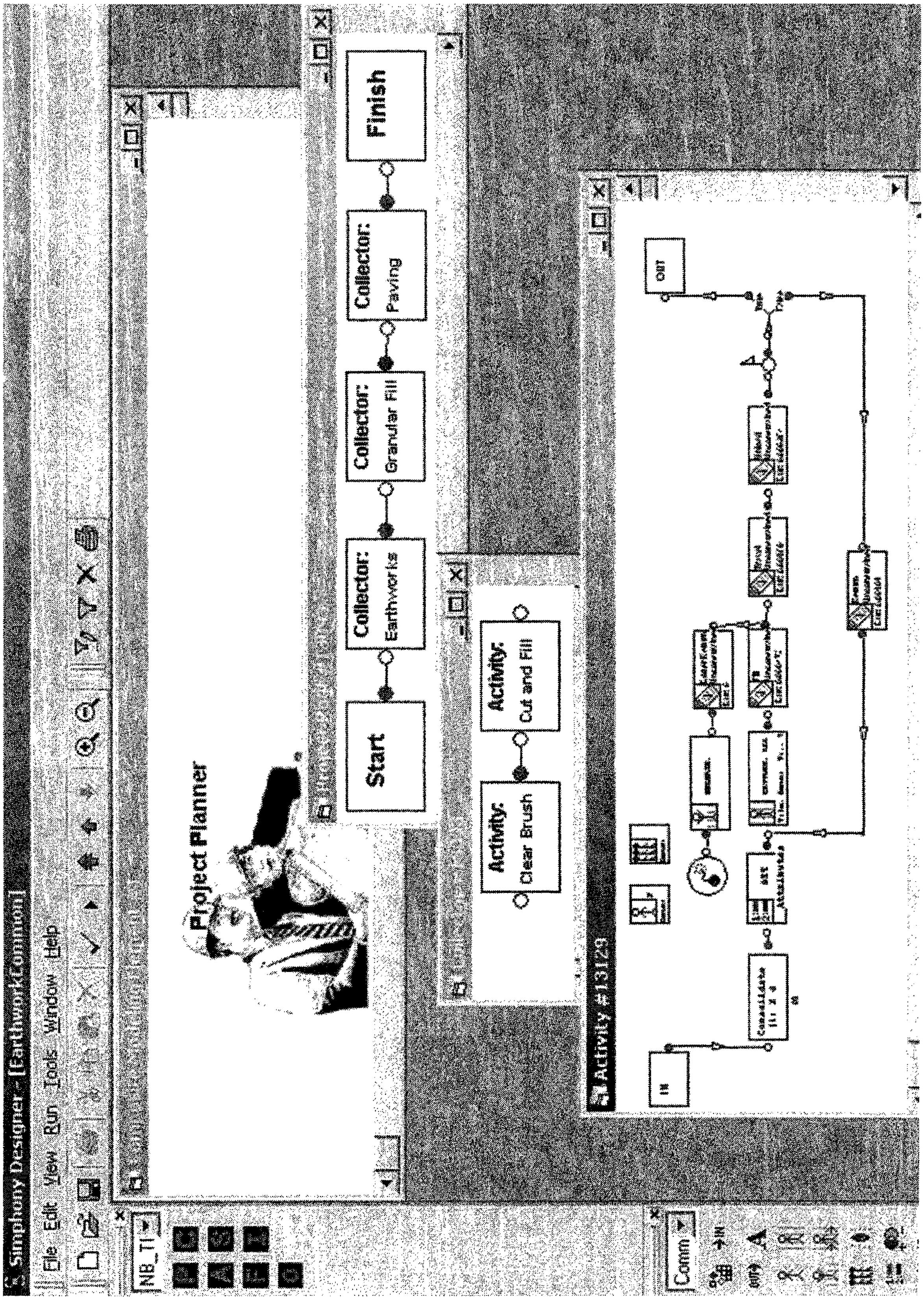

Figure 4:1 - Earthwork Operations Modeled in Network Diagram

The logic of the operation in relationship to the network diagram is that when the required amount of fill has been dumped at the dump site, the activity is complete, and the next activity in the network diagram can proceed.

After running the simulation model, the output duration for the earthwork operation was 2.42 working days. This value would then used as the duration for the 'Cut and Fill' activity in the network diagram, instead of manually entering in a value into the *activity* elements' parameters.

4.5 CONCLUSION

A SPS tool was developed in the simulation environment Simphony. The SPS tool, called the planning template, incorporates all of the project analysis methodology discussed in Chapter 2. The planning template allows for easy creation of simulation models, providing a tool for project analysts that is efficient, reusable, reliable, and accurate.

CHAPTER 5: MODEL IMPLEMENTATION AND CASE STUDY

5.1 INTRODUCTION

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 modeling 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.

It should be noted that in the following chapter the term 'range estimate' will be used. Range estimate should be understood as the application of Monte Carlo techniques to project costs and revenues.

5.2 COST ESTIMATE MODELS DEVELOPED

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 modeled project's time of occurrence. The fourth model was modeled to start August 1, 2002, while the sixth model was modeled to occur beginning October 1, 2011. The reason this was done was so a comparison of the long term effect on using a forecasted inflation (which is model seven) versus a subjective inflation rate (which is model six) could be made 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. The complete set of input data can be viewed in Appendix F.

5.3 ANALYSIS PROCEDURE

Upon determining the project network sequencing, the project network was inputted into the developed SPS tool in the simulation environment Simphony, for the discussed models. Figure 5:1 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.

5.4 SUMMARY OF SIMULATION RESULTS

The results of the simulation analysis are summarized in Table 5:1. A complete table of results can be seen in Appendix G. Figure 5:2 shows the cumulative distribution function (CDF) for the range estimate plus forecasted inflation costs.

For complete graphical results see Appendix H.

5.5 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

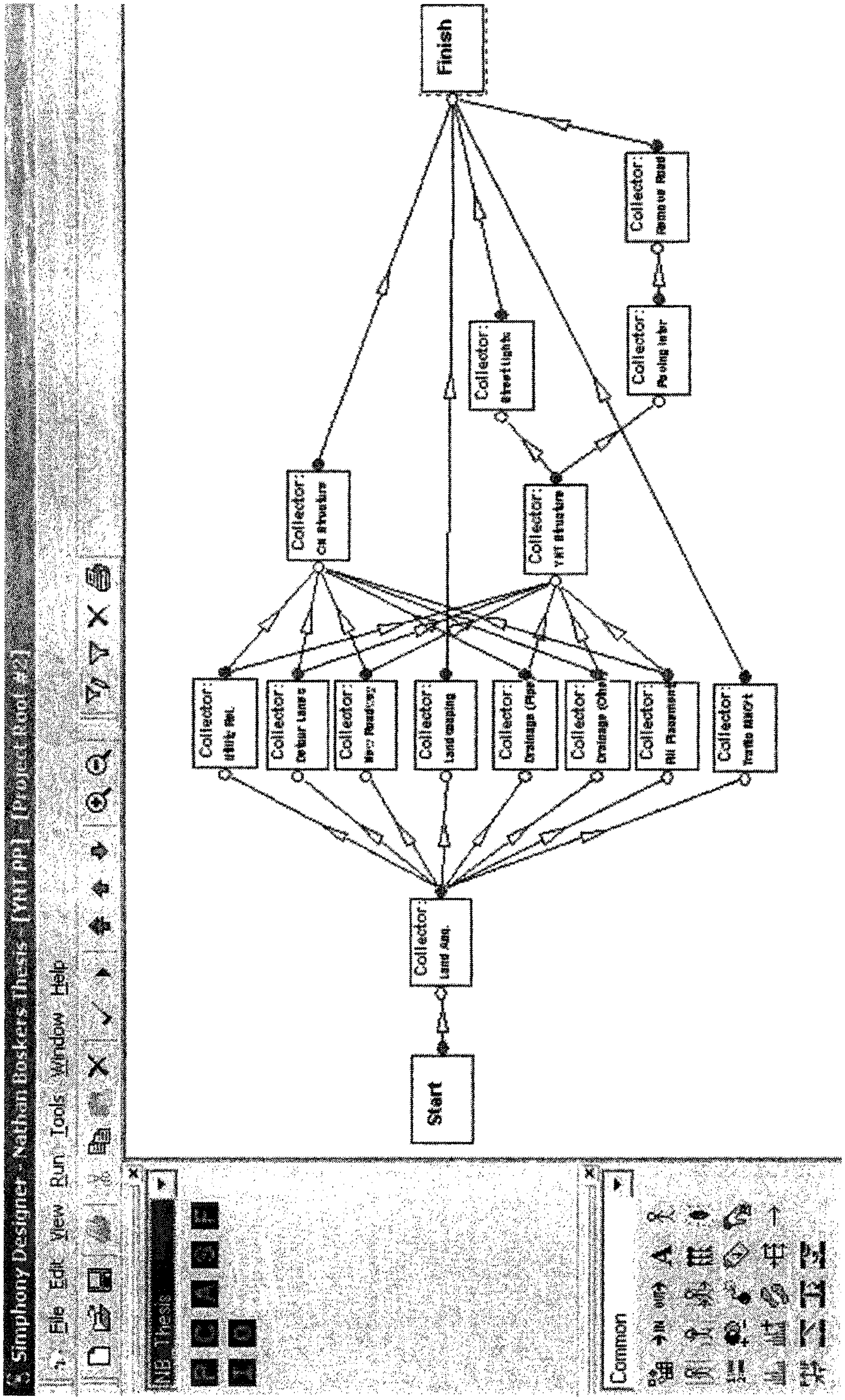

Figure 5:1 - Case Study Network Diagram

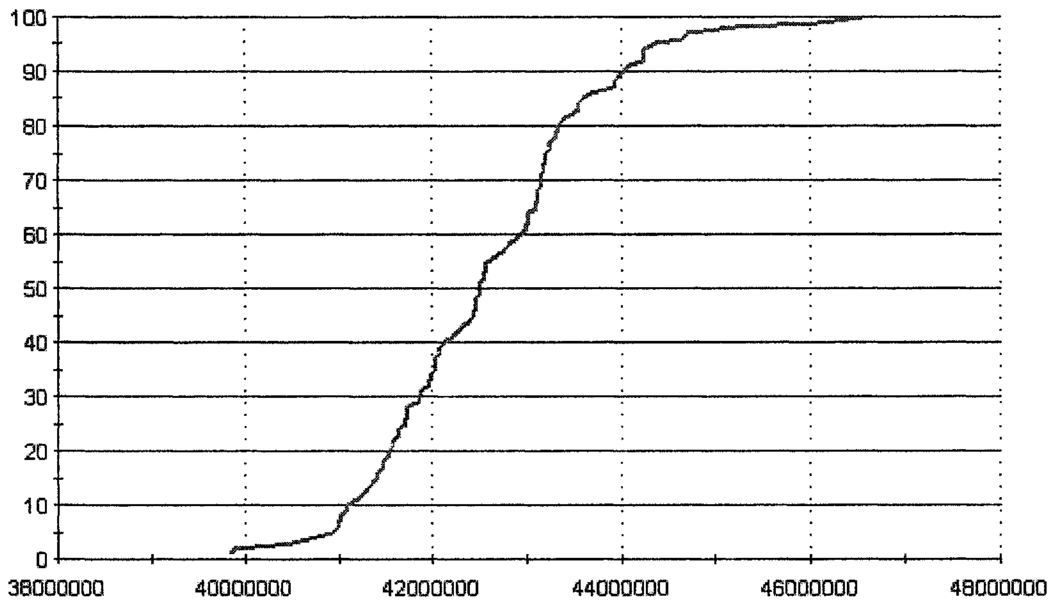

Figure 5:2 - CDF for Range Estimate with Forecasted Inflation

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 $\pm$ 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. Appendix I contains a table of the activities listed in rank of their cost.

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

Table 5:1 - Simulation Results

5.6 CONCLUSION

Range estimating and network analysis techniques were used to analyze 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.

CHAPTER 6: CONCLUSION

6.1 SUMMARY OF WORK

The decisions made in regards to capital investment prior to the commitment of large amounts of capital, and the decisions made before much of the project's life has occurred, are the most important decisions an analyst can face. The decisions made at the early stages of a project have large impacts on the future outcome of the project. This is especially true when considering the economics of the project. Incorrect decisions made at the early stages of a project could result in large amounts of economic losses in the future. Therefore, vigorous, detailed, and accurate analysis needs to be done on potential capital investment projects, as well as committed projects in their early lives, in order to ensure that risk is minimized, due to the impacts that wrong decisions can make.

Current analysis methods used in industry do not explicitly consider the inherent uncertainty in future conditions. Specifically, future project cash flows are assumed to be known with certainty, and are assigned fixed values as input for analysis methods. Current analysis methods used in academics fail to properly consider all the uncertainties in future cash flow conditions. Here, researchers have been limited to current technology when trying to enhance the current techniques, namely the spreadsheet type software program.

The work done in this thesis used an advanced computer simulation environment called Simphony, which allows for the development of much more detailed analytical models than a spreadsheet type program could ever create. A special purpose simulation (SPS) tool was developed in order to be able to better analyze projects than current analytical techniques allow for. Some current academic analysis techniques, namely Monte Carlo techniques, were also incorporated into the developed tool. Some enhancements to the current techniques were developed due to the use of Simphony. The main contribution that was realized due to the use of Simphony was the incorporation of network analysis to the overall analysis of future cash flows. Previously, the timing of the cash flow occurrence, as well as the duration of individual cash flows within a project's duration, were always deterministic. The developed SPS tool allows for stochastic activity durations, which in turn changes the project's cash flows for each simulation run.

In addition to developing an improved tool with enhanced features not realized before, contributing work was also realized in developing a methodology for being able to better estimate future cash flows, as it is the cash flows as input that totally affects the accuracy of the output. By using a time-series forecasting technique, future inflation rates were forecasted and could be used to forecast future cash flows in actual dollars. Current industry standard is to subjectively select an inflation rate. This rate may be based on the analysts personal experience, however, it is not selected mathematically. Using the Box-Jenkins forecasting technique, future inflation rates can be forecasted purely from historical data, and are free from personal subjective bias.

By incorporating the enhanced simulation techniques developed with the methodology for better forecasting of future cash flows, a new tool and analytical procedure was created to be able to better the analysis of capital investment projects.

6.2 LIMITATIONS OF RESEARCH

The limitations to the current methodology used to forecast future cash flows lies in the costs due to interest, or the cost due to financing a project. Ranasinghe's (1996) formulas incorporate this cost in the *TPC*. In the research conducted here, it was assumed that the formula developed by Ranasinghe was adequate. However, just as the future inflation rate is unknown, so is the future interest rate. Research was not done to see if the time-series analysis used to forecast the future inflation rate could be used to forecast future interest rates. Like the costs due to inflation, the cost of financing is an extremely important cost to incorporate into the overall cash flows. Therefore, further work should be done to develop a method for properly being able to forecast future interest rates, so that costs due to project financing can be forecasted with some degree of certainty. Again, it needs to be stressed, as throughout this research, that input as logical and objective as possible needs to be used in the analysis techniques to ensure that the output attained has some credible merit.

Another limitation to the research done, as well as all the previous research, is the lack of ability for the analyst to model economic market randomness. What is meant here is that things such as stock market crashes, which cause things such as interest and inflation rates to not follow their regular patterns of history, have not been in the past, and are not currently incorporated into the simulation models developed. Recall that in forecasting the future inflation rate using the Box-Jenkins methodology that the events due to September 11, 2001 were disregarded due to the irregular effect they had on the CPI index. However, in reality these events do occur, and at some point an analyst will want to perform sensitivity analysis to see what kind of effect a large random event may have on the outcome of a project. In some cases, this random event may be significant enough that the decision makers may not want to take any kind of risk in investing capital due to the effects caused by a freak event. Future work should be done to somehow incorporate the possibility of random irregular market events.

Some limitations to the developed tool exist. The first limitation to the tool is that it only incorporates finish-to-start relationships in the network activities. Not all activities have a finish-to-start relationship. For example, a project management activity may have a finish-to-finish relationship with a construction activity, because when the construction is complete, so is the project management activity. However this cannot be modeled in the developed SPS tool. In addition to this tool limitation, a limitation also exists in modeling the financing of the project. Financing costs are generally interest paid on the money remaining when the sum of the costs is larger than the sum of the revenues. The developed model does not incorporate the cost due to financing. The tool needs to be further developed to incorporate this cost.

6.3 FUTURE RESEARCH

Further research needs to be done to continue to make the project analysis techniques more dependable. The limitations in the research conducted here needs to be addressed and accounted for to make the current analysis technique more vigorous. All the CPM relationships need to be incorporated into the SPS tool, a forecasting technique needs to be developed for forecasting future interest rates, and the SPS tool needs to be enhanced to incorporate possible market randomness, which could then be used for sensitivity analysis.

In regards to the Box-Jenkins methodology, it is not possible at this time to state for a fact that this method for forecasting is actually a more accurate method than using subjective personal judgment. This could only be determined by forecasting a future inflation rate using the Box-Jenkins methodology, and comparing the results to the results of an analyst predicting future rates for the same time period. It would require a test to make this comparison, with the test taking a long time, as inflation rate patterns fluctuate over large time periods. However, it can be suggested that the forecast would be somewhat different, because of information that the two different techniques are using to predict the future rates. Using subjective personal judgment, an analyst views current events locally and globally to predict the rates, versus the Box-Jenkins methodology using purely historical patterns. For example, an analyst predicting a future inflation rate can incorporate social and political events, such as the possibility of a major war breaking out, into the future prediction. The Box-Jenkins methodology could not incorporate this information into the analysis. Although at this time it is not possible to know which method is better than the other, it is known that both methods use valuable information for predicting the rates. The Box-Jenkins methodology is mathematical, and incorporates seasonal trends, whereas the subjective rate incorporates things that are not quantifiable and subjective in nature, such as current events. Knowing then that both methods have important features, a method that incorporates the features from both would be ideal.

One possible way to do this would be to combine the two methods into some sort of hybrid forecasting system. This could possibly be done by combining the Box-Jenkins methodology with an expert system, which would then allow for personal subjective reasoning to also affect the forecasted future inflation rate. Further work should be done to see if this is possible.

6.4 CONCLUSION

Overall, the research conducted here has contributed to the current methods and techniques used in capital investment analysis of projects. Current academic methodologies were enhanced by the use of time-series forecasting techniques in order to make the future cash flows more objective in nature. The current tools and analytical techniques were enhanced and expanded upon by the creation of a SPS tool. Further work still needs to be done to enhance the methodologies and tools used in the analysis procedure of capital investment analysis.

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APPENDIX A: CHI-SQUARED DISTRIBUTION

Degrees of	Confidence			
Freedom	0.10	0.05	0.025	0.01
1	2.706	3.841	5.024	6.635
2	4.605	5.991	7.378	9.210
3	6.251	7.815	9.348	11.345
4	7.779	9.488	11.143	13.277
5	9.236	11.070	12.833	15.086
6	10.645	12.592	14.449	16.812
7	12.017	14.067	16.013	18.475
8	13.362	15.507	17.535	20.090
9	14.684	16.919	19.023	21.666
10	15.987	18.307	20.483	23.209
11	17.275	19.675	21.920	24.725
12	18.549	21.026	23.337	26.217
13	19.812	22.362	24.736	27.688
14	21.064	23.685	26.119	29.141
15	22.307	24.996	27.488	30.578
16	23.542	26.296	28.845	32.000
17	24.769	27.587	30.191	33.409
18	25.989	28.869	31.526	34.805
19	27.204	30.144	32.852	36.191
20	28.412	31.410	34.170	37.566
21	29.615	32.671	35.479	38.932
22	30.813	33.924	36.781	40.289
23	32.007	35.172	38.076	41.638
24	33.196	36.415	39.364	42.980
25	34.382	37.652	40.646	44.314
26	35.563	38.885	41.923	45.642
27	36.741	40.113	43.195	46.963
28	37.916	41.337	44.461	48.278
29	39.087	42.557	45.722	49.588
30	40.256	43.773	46.979	50.892

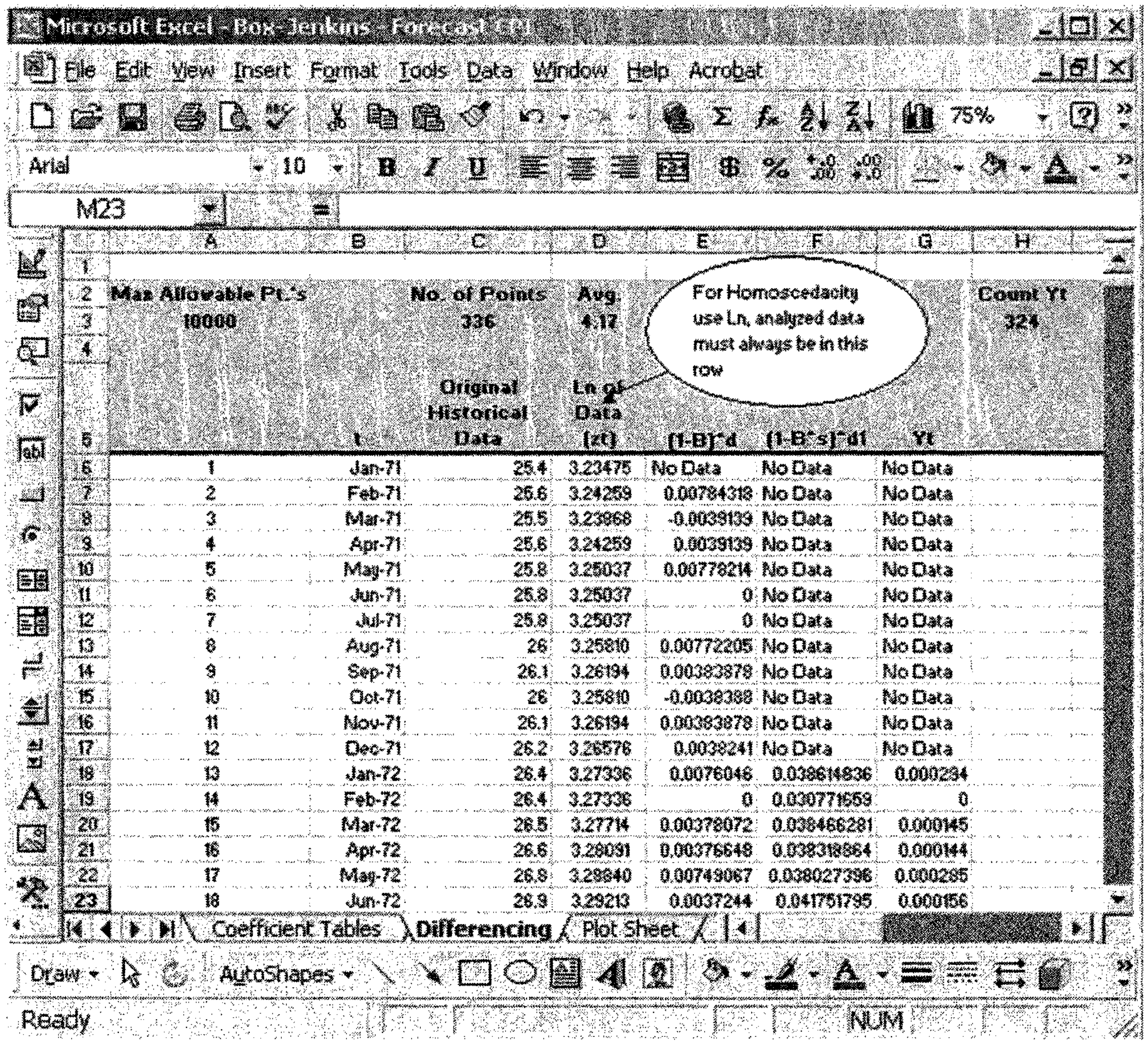
Table A:1 - Chi-Squared Distribution

APPENDIX B: CALCULATION OF SAMPLE AUTOCORRELATION'S AND CHI-SQUARE STATISTIC

The calculation of the sample autocorrelations and for the chi-square statistic was done using the aid of the spreadsheet program Microsoft Excel (Microsoft 2000). Due to the nature of the algorithms that needed to be solved, entering a single formula into a cell was not an adequate means of performing many types of calculations. Because the back shift operator changes the actual algorithm (or formula in a cell), special VBA code had to be written to automate this process.

For the calculation of the SAC's, the first step the user must do is to input the data in the sheet titled "Differencing". Once this is done, the user must then proceed to the sheet called "Step 1 – Identification", where the user must input the differencing that is desired (i.e. d=0 and d1=2). Once these values are inputted, a command button exists that when clicked on will perform the differencing calculations, the SAC values, and the SPAC values. In addition to these, plots of the differenced data series, the SACF and the SPACF's are generated. Figures B:1 and B:2 show what the two sheets look like.

For the calculation of the Chi-Square statistic, the first step the user must do is input the residuals, a_t, into the sheet titled "Diagnostic Checking", in addition to this on the same sheet the user must input the ARIMA parameters. Once this is done the user can click on the command button on this sheet, which will calculate the Chi-Square statistic, Q, the degrees of freedom, and the SAC's and the SAC's squared. In addition to this, a plot of the SACF for the residuals is also generated. Figure B:3 shows what this sheet looks like.



	A	B	C	D	E	F	G	H
1								
2	Max Allowable Pt.'s		No. of Points	Avg.				Count Yt
3	10000		336	4.17				324
4								
5		t	Original Historical Data	Ln of Data [zt]	[1-B]^d	[1-B^s]^d1	Yt	
6	1	Jan-71	25.4	3.23475	No Data	No Data	No Data	
7	2	Feb-71	25.6	3.24259	0.00784318	No Data	No Data	
8	3	Mar-71	25.5	3.23868	-0.0039139	No Data	No Data	
9	4	Apr-71	25.6	3.24259	0.0039139	No Data	No Data	
10	5	May-71	25.8	3.25037	0.00778214	No Data	No Data	
11	6	Jun-71	25.8	3.25037	0	No Data	No Data	
12	7	Jul-71	25.8	3.25037	0	No Data	No Data	
13	8	Aug-71	26	3.25810	0.00772205	No Data	No Data	
14	9	Sep-71	26.1	3.26194	0.00383878	No Data	No Data	
15	10	Oct-71	26	3.25810	-0.0038388	No Data	No Data	
16	11	Nov-71	26.1	3.26194	0.00383878	No Data	No Data	
17	12	Dec-71	26.2	3.26576	0.0038241	No Data	No Data	
18	13	Jan-72	26.4	3.27336	0.0076046	0.038614836	0.000294	
19	14	Feb-72	26.4	3.27336	0	0.030771659	0	
20	15	Mar-72	26.5	3.27714	0.00378072	0.038466281	0.000145	
21	16	Apr-72	26.6	3.28091	0.00376648	0.038318864	0.000144	
22	17	May-72	26.8	3.28840	0.00749067	0.038027396	0.000285	
23	18	Jun-72	26.9	3.29213	0.0037244	0.041751795	0.000156	

Figure B:1 - Differencing Sheet

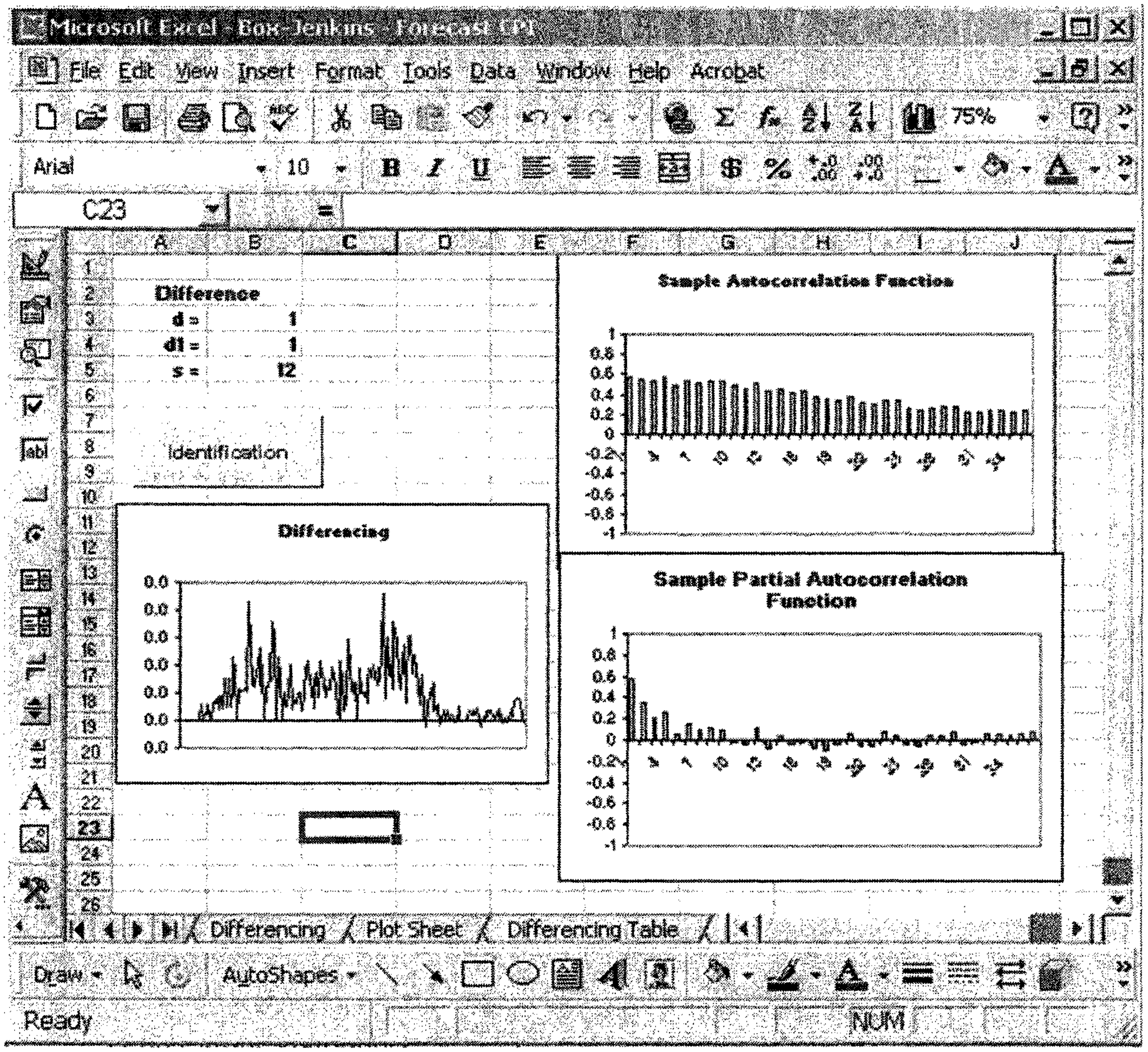


Figure B:2 - Step 1 – Identification Sheet

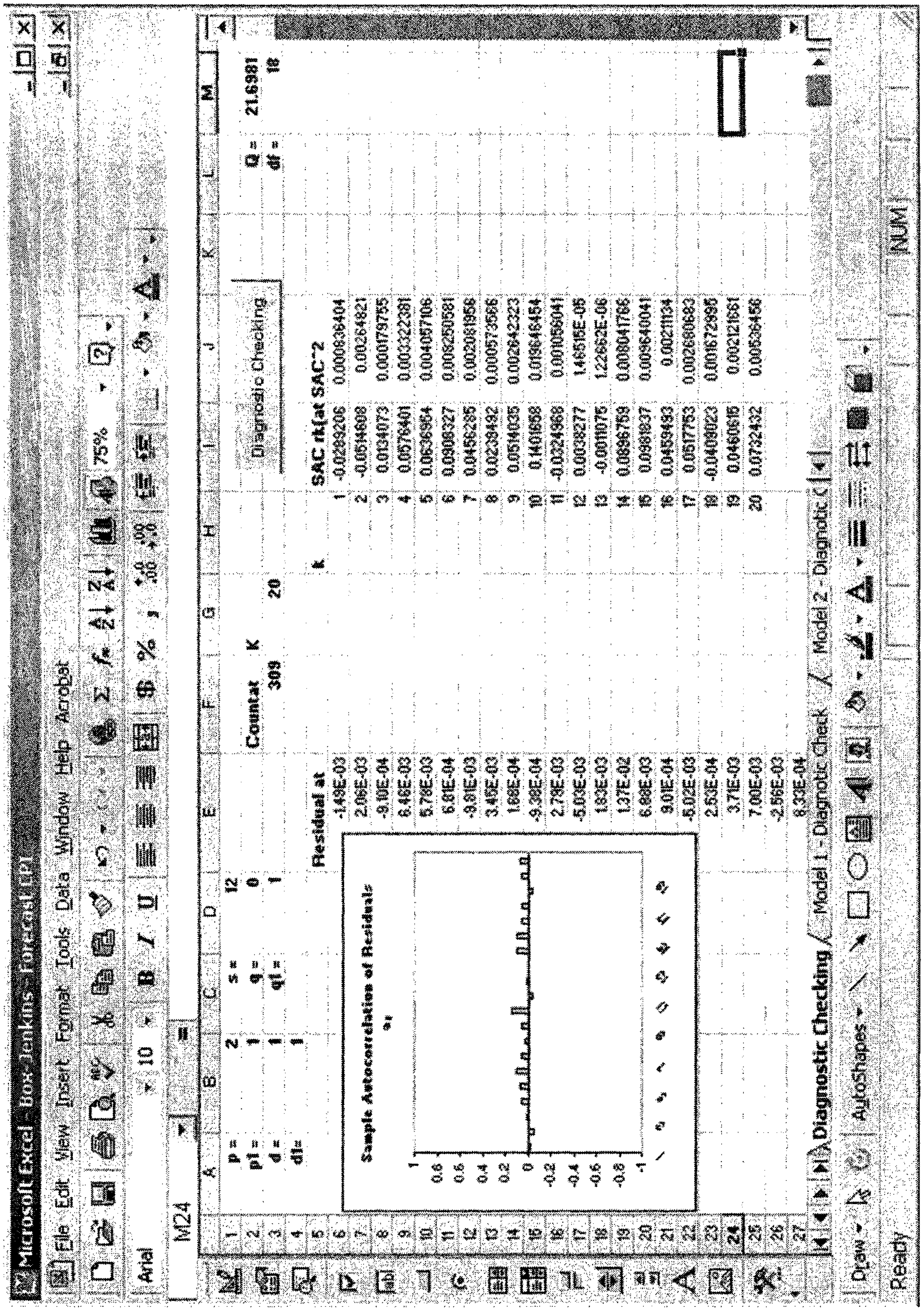


Figure B:3 - Diagnostic Checking Sheet

B.1 DEVELOPED DIFFERENCING AND SAMPLE AUTOCORRELATION COMPUTATION COMPUTER CODE

```
Private Sub CommandButton1_Click()

Dim CountYt1 As Integer
Dim CountData3 As Integer
Dim OrigArray()
Dim OrigDataArray()
Dim OrigDataLNArray()

Sheet2.Select                                   'Activate "Differencing" sheet
ActiveSheet.Range("e6:e10006").Clear            '******clear col before performing calc.
ActiveSheet.Range("f6:f10006").Clear            '******must change the no. of rows in the
col.****
ActiveSheet.Range("g6:g10006").Clear

'PERFORM DIFFERENCING
Call RegularDifference
Call SeasonalDifference
Call Difference

'CREATE AN ARRAY CONTAINING THE CALCULATED Yt
Sheet2.Select
CountYt1 = ActiveSheet.Cells(3, 3)
CountData3 = ActiveSheet.Cells(3, 3)
ReDim OrigArray(CountYt1 - 1, 0)
ReDim OrigDataArray(CountData3 - 1, 0)
ReDim OrigDataLNArray(CountData3 - 1, 0)

For t = 0 To CountYt1 - 1
    OrigArray(t, 0) = ActiveSheet.Cells(t + 6, 7)
Next t
For t = 0 To CountData3 - 1
    OrigDataArray(t, 0) = ActiveSheet.Cells(t + 6, 3)
Next t
For t = 0 To CountData3 - 1
    OrigDataLNArray(t, 0) = ActiveSheet.Cells(t + 6, 4)
Next t



'PRINT Yt DATA, ORIGDATA, & ORIGLNDATA IN "SAC CALCULATION" SHEET
Sheet5.Select
ActiveSheet.Range("c6:c10006").Clear
ActiveSheet.Range("d6:d10006").Clear
ActiveSheet.Range("e6:e10006").Clear
For t = 0 To CountData3 - 1
    ActiveSheet.Cells(t + 6, 3) = OrigDataArray(t, 0)
Next t
For t = 0 To CountData3 - 1
    ActiveSheet.Cells(t + 6, 4) = OrigDataLNArray(t, 0)
Next t
For t = 0 To CountYt1 - 1
    ActiveSheet.Cells(t + 6, 5) = OrigArray(t, 0)
Next t

'CALCULATE THE SAC'S AND SPAC'S
Call SAC_Calculation
Call SPAC_Calculation

Sheet3.Select

End Sub
Sub SAC_Calculation()

'DECLARATIONS
Dim r As Double, t As Integer, K, p As Integer
Dim int1 As Integer, CountData, CountYt, ND As Integer, A As Double, b As Double
```

```
Dim avgY As Double, tt As Integer, SP As Integer

'PRELIMINARY DEFINITIONS
Sheet5.Select
ActiveSheet.Range("h6:h10006").Clear                    'display k values for graphical
purposes
CountData = ActiveSheet.Cells(3, 3)
CountYt = ActiveSheet.Cells(3, 6)
ND = CountData - CountYt                                        'SP is starting point
cell


'WRITE 1 THROUGH COUNTYT-1
For int1 = 1 To CountYt - 1
    ActiveSheet.Cells(int1 + 5, 8) = int1
Next int1

'CALCULATE AVERAGE Yt (note that avgY is for the sample size only, not all Y's)
avgY = 0
For tt = 1 To CountYt
    avgY = avgY + ActiveSheet.Cells(tt + ND + 5, 5)
Next tt
avgY = avgY / CountYt

'CALCULATE SAC DENOMINATOR b
b = 0
For tt = 1 To CountYt
    b = b + ((ActiveSheet.Cells(ND + tt + 5, 5) - avgY) ^ 2)
Next tt

ActiveSheet.Range("i6:i10006").Clear

For p = 1 To CountYt - 1
    A = 0

        'CALCULATE SAC NUMERATOR A
        For t = 1 To CountYt - p
            A = A + ((ActiveSheet.Cells(ND + t + 5, 5) - avgY) * (ActiveSheet.Cells(ND + t
+ p + 5, 5) - avgY))
        Next t

    'CALCULATE SAC rk
    r = A / b
    ActiveSheet.Cells(p + 5, 9) = r
Next p

End Sub

Sub SPAC_Calculation()

Dim Aarray() As Double
Dim K, j, r, A, count, d, p, q, c, f, kk, int1 As Integer
Dim CountYt As Integer

Sheet5.Select
ActiveSheet.Range("k6:l10006").Clear
count = ActiveSheet.Cells(3, 3)
CountYt = ActiveSheet.Cells(3, 6)
d = CountYt - 2
ReDim Aarray(d, d)

Aarray(0, 0) = ActiveSheet.Cells(6, 9)

For K = 2 To CountYt - 1

        kk = 0
        c = 0
        f = 0

        For j = 1 To K - 1
            c = c + ((Aarray(K - 2, j - 1)) * ActiveSheet.Cells(K - j + 5, 9))
```

```
        Next j

        For j = 1 To K - 1
            f = f + ((Aarray(K - 2, j - 1)) * ActiveSheet.Cells(j + 5, 9))
        Next j

        kk = (ActiveSheet.Cells(K + 5, 9) - c) / (1 - f)
        Aarray(K - 1, K - 1) = kk

        For j = 1 To K - 1
            Aarray(K - 1, j - 1) = Aarray(K - 2, j - 1) - ((Aarray(K - 1, K - 1)) *
Aarray(K - 2, K - j - 1))
        Next j

Next K


For int1 = 1 To CountYt - 1
    ActiveSheet.Cells(int1 + 5, 11) = int1
Next int1

For int1 = 1 To CountYt - 1                           'write SPAC
    ActiveSheet.Cells(int1 + 5, 12) = Aarray(int1 - 1, int1 - 1)
Next int1

End Sub
Sub Difference()

Dim n2 As Double, intJ2 As Integer, a2 As Double

Sheet2.Select
n2 = ActiveSheet.Cells(3, 3).Value + 5
If ActiveSheet.Cells(2, 11) = 0 And ActiveSheet.Cells(3, 11) = 0 Then
    For intJ2 = 6 To n2
        ActiveSheet.Cells(intJ2, 7) = ActiveSheet.Cells(intJ2, 4) - ActiveSheet.Cells(3, 4)
    Next intJ2
Else
    If ActiveSheet.Cells(2, 11) = 0 And ActiveSheet.Cells(3, 11) <> 0 Then
        For intJ2 = 6 To n2
            ActiveSheet.Cells(intJ2, 7) = ActiveSheet.Cells(intJ2, 6)
        Next intJ2
    Else
        If ActiveSheet.Cells(2, 11) <> 0 And ActiveSheet.Cells(3, 11) = 0 Then
            For intJ2 = 6 To n2
                ActiveSheet.Cells(intJ2, 7) = ActiveSheet.Cells(intJ2, 5)
            Next intJ2
        Else
            For intJ2 = 6 To n2                  'if d1 and d do not equal 0
                If ActiveSheet.Cells(intJ2, 5) = "No Data" Or ActiveSheet.Cells(intJ2, 6) =
"No Data" Then
                    ActiveSheet.Cells(intJ2, 7) = "No Data"
                Else
                    a2 = ActiveSheet.Cells(intJ2, 5) * ActiveSheet.Cells(intJ2, 6)
                    ActiveSheet.Cells(intJ2, 7) = a2
                End If
            Next intJ2
        End If
    End If
End If

End Sub
Sub RegularDifference()

Dim CoTab() As Integer                          'Define an array with no dimensions
Dim ZArray() As Double
Dim K As Double, intI As Integer, i As Integer, N As Integer
Dim s As Integer, intJ As Integer, f As Integer, h As Integer
Dim A As Integer, b As Integer, c As Double, e As Integer
Dim p As Double, test As Double
```

```
Sheet2.Select                                    'Activate Differencing sheet
K = ActiveSheet.Cells(2, 11).Value                'k = d
ReDim CoTab(0, K)                                'Define CoTab dimensions
ReDim ZArray(K, 0)                               'Define ZArray dimensions


Sheet1.Select                                    'Activate "Coeffient Tables" sheet
i = 0

For intI = 1 To K + 1                            'Loop to define CoTab array
    CoTab(0, i) = ActiveSheet.Cells(K + 32, i + 2).Value
    i = i + 1
Next intI

Sheet2.Select                                    'Activate "Differencing" sheet
N = ActiveSheet.Cells(3, 3).Value + 5

ActiveSheet.Range("e6:e10006").Clear              '******delete col before performing calc.
ActiveSheet.Range("f6:f10006").Clear              '******must change the no. of rows in the
col.****

For intJ = 6 To N                                'Loop to calc. (1-B)^d value
b = 0
e = 0
c = 0
    For g = 0 To K                               'Check if amount of seasonal differencing
is even feasible with the amount of data
            If intJ - g < 6 Then
                ActiveSheet.Cells(intJ, 5) = "No Data"
            Else
                End If

    Next g

    If ActiveSheet.Cells(intJ, 5) <> "No Data" Then

            For f = 0 To K                               'Generate remaining ZArray
                p = intJ - f
                ZArray(f, 0) = ActiveSheet.Cells(p, 4)
            Next f

        For A = 1 To K + 1                       'Perform matrix multiplication for this
cell
            c = c + (CoTab(0, b) * ZArray(e, 0))
            b = b + 1
            e = e + 1
        Next A
        ActiveSheet.Cells(intJ, 5) = c
    Else
        End If

Next intJ
End Sub
Sub SeasonalDifference()

Dim CoTab1() As Integer                           'Define an array with no dimensions
Dim ZArray1() As Double
Dim K1 As Double, intI1 As Integer, i1 As Integer, n1 As Integer
Dim s1 As Integer, intJ1 As Integer, f1 As Integer, h1 As Integer
Dim a1 As Integer, b1 As Integer, c1 As Double, e1 As Integer
Dim p1 As Double, test1 As Double


Sheet2.Select                                    'Activate Differencing sheet
K1 = ActiveSheet.Cells(3, 11).Value                'k = d1
ReDim CoTab1(0, K1)                               'Define CoTab1 dimensions
ReDim ZArray1(K1, 0)                              'Define ZArray1 dimensions
```

```
Sheet1.Select                                           'Activate "Coeffient Tables" sheet
i1 = 0

For intI1 = 1 To K1 + 1                                   'Loop to define CoTab1 array
    CoTab1(0, i1) = ActiveSheet.Cells(K1 + 32, i1 + 2).Value
    i1 = i1 + 1
Next intI1

Sheet2.Select                                           'Activate "Differencing" sheet
n1 = ActiveSheet.Cells(3, 3).Value + 5
s1 = ActiveSheet.Cells(4, 11).Value

ActiveSheet.Range("f6:f10006").Clear                      '******delete col before performing calc.
                                                        '******must change the no. of rows in the
col.****

For intJ1 = 6 To n1                                       'Loop to calc. (1-B^s)^d1 value
b1 = 0
e1 = 0
c1 = 0
    For g1 = 0 To K1                                     'Check if amount of seasonal differencing
is even feasible with the amount of data
            If intJ1 - (s1 ^ g1) < 6 Then
                ActiveSheet.Cells(intJ1, 6) = "No Data"
            Else
                End If

    Next g1

    If ActiveSheet.Cells(intJ1, 6) <> "No Data" Then
        ZArray1(0, 0) = ActiveSheet.Cells(intJ1, 4)       'For first row/col
        h1 = 1
            For f1 = 1 To K1                             'Generate remaining ZArray1
                p1 = intJ1 - (s1 ^ h1)
                test1 = p1
                ZArray1(f1, 0) = ActiveSheet.Cells(p1, 4)
                h1 = h1 + 1
            Next f1

        For a1 = 1 To K1 + 1                              'Perform matrix multiplication for this
cell
            c1 = c1 + (CoTab1(0, b1) * ZArray1(e1, 0))
            b1 = b1 + 1
            e1 = e1 + 1
        Next a1
        ActiveSheet.Cells(intJ1, 6) = c1
    Else
        End If

Next intJ1

End Sub
```

B.2 DEVELOPED CHI-SQUARE TEST CODE

```
Private Sub CommandButton1_Click()

Call SACResidual_Calculation
Call SACSquared_Calc
Call Chi_Square_Calc

End Sub

Sub SACResidual_Calculation()

'DECLARATIONS
Dim r As Double, t As Integer, K, p As Integer
```

```
Dim int1 As Integer, CountData, Countat, ND As Integer, A As Double, b As Double
Dim avgat As Double, tt As Integer, SP As Integer
Dim K2 As Integer

'PRELIMINARY DEFINITIONS
Sheet6.Select
ActiveSheet.Range("h6:h10006").Clear                    'display k values for graphical
purposes
CountData = ActiveSheet.Cells(3, 3)
Countat = ActiveSheet.Cells(3, 6)
K2 = ActiveSheet.Cells(3, 7)

'WRITE 1 THROUGH K
For int1 = 1 To K2
    ActiveSheet.Cells(int1 + 5, 8) = int1
Next int1

'CALCULATE AVERAGE at (note that avgat is for the sample size only, not all a's)
avgat = 0
For tt = 1 To Countat
    avgat = avgat + ActiveSheet.Cells(tt + 5, 5)
Next tt
avgat = avgat / Countat

'CALCULATE SAC DENOMINATOR b
b = 0
For tt = 1 To Countat
    b = b + ((ActiveSheet.Cells(tt + 5, 5) - avgat) ^ 2)
Next tt

ActiveSheet.Range("i6:i10006").Clear

For p = 1 To K2
    A = 0

        'CALCULATE SAC NUMERATOR A
        For t = 1 To Countat - p
            A = A + ((ActiveSheet.Cells(t + 5, 5) - avgat) * (ActiveSheet.Cells(t + p + 5,
5) - avgat))
        Next t

    'CALCULATE SAC rk
    r = A / b
    ActiveSheet.Cells(p + 5, 9) = r
Next p

End Sub
Sub SACSquared_Calc()

Dim K1, t As Integer

ActiveSheet.Range("j6:j10006").Clear
K1 = ActiveSheet.Cells(3, 7)

'CALCULATE RESIDUAL SAC SQUARED
For t = 1 To K1
    ActiveSheet.Cells(t + 5, 10) = (ActiveSheet.Cells(t + 5, 9)) ^ 2
Next t

End Sub

Sub Chi_Square_Calc()

Dim Chi, df As Double, N, n1, n2 As Integer, K As Integer, at As Double
Dim p, p1, d, d1, s, q, q1 As Integer
Dim countat2 As Integer
Dim SumResid, t As Integer

'PRELIMINARY DEFINITIONS
Sheet6.Select
p = ActiveSheet.Cells(1, 2)
```

```
p1 = ActiveSheet.Cells(2, 2)
d = ActiveSheet.Cells(3, 2)
d1 = ActiveSheet.Cells(4, 2)
s = ActiveSheet.Cells(1, 4)
q = ActiveSheet.Cells(2, 4)
q1 = ActiveSheet.Cells(3, 4)
countat2 = ActiveSheet.Cells(3, 6)
K = ActiveSheet.Cells(3, 7)

'CALCULATE n (n IS MAX BACK ORDER)
n1 = p + (p1 * s) + d + (d1 * s)
n2 = q + (q1 * s)
If n1 > n2 Or n1 = n2 Then
    N = countat2 - n1
Else
    N = countat2 - n2
End If

'CALCULATE SUM OF RESIDUALS
SumResid = 0
For t = 1 To K
    SumResid = SumResid + ActiveSheet.Cells(t + 5, 10)
Next t

'CALCULATE CHI-SQUARED STATISTIC
Chi = N * SumResid

'CALCULATE df
df = K - p - q

'WRITE CHI AND df
ActiveSheet.Cells(2, 13) = Chi
ActiveSheet.Cells(3, 13) = df


End Sub
```

APPENDIX C: SACF'S, SPACF'S, AND DIFFERENCING PLOTS

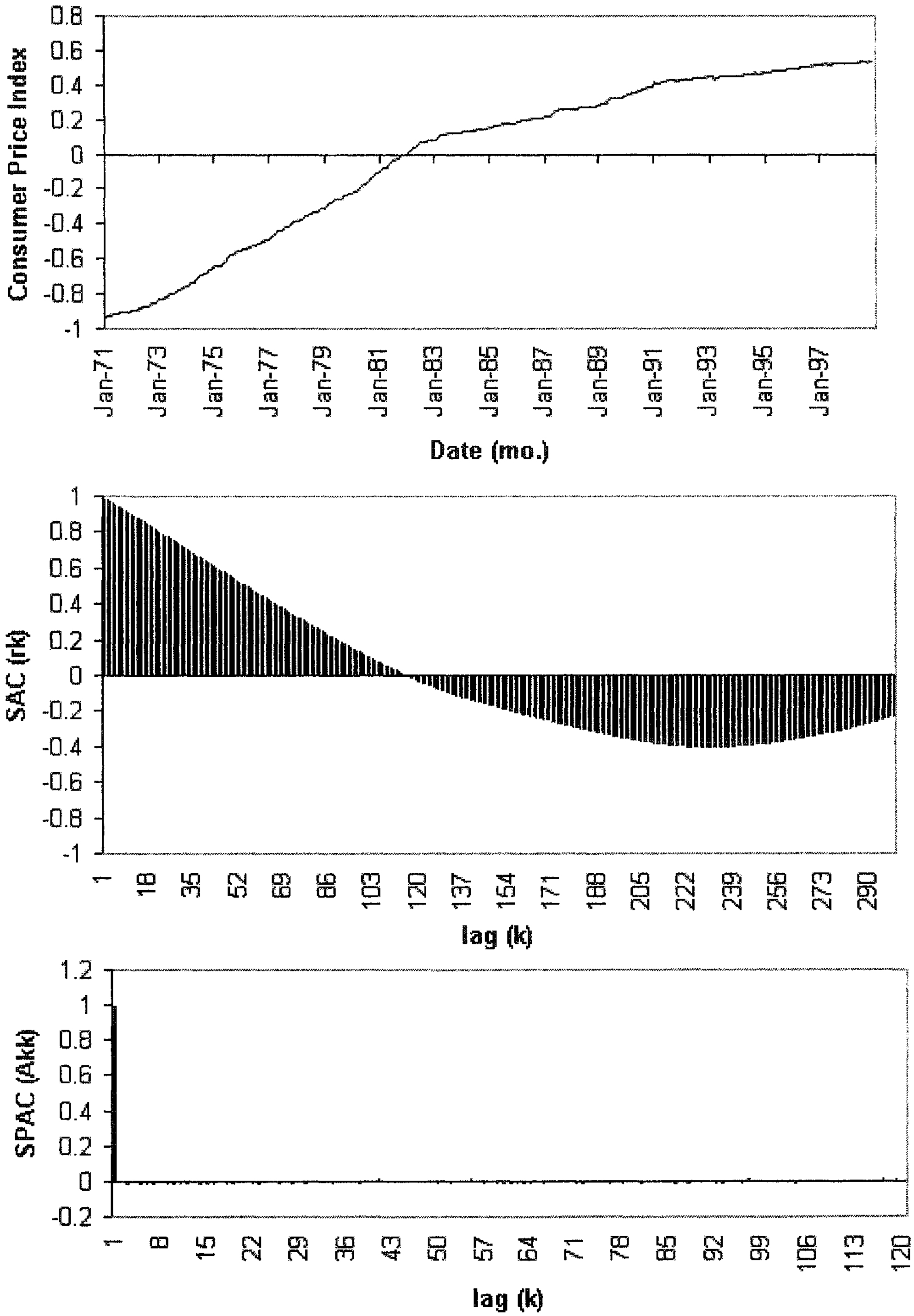


Figure C:1 - Differencing, SACF and SPACF Plots with Zero Differencing

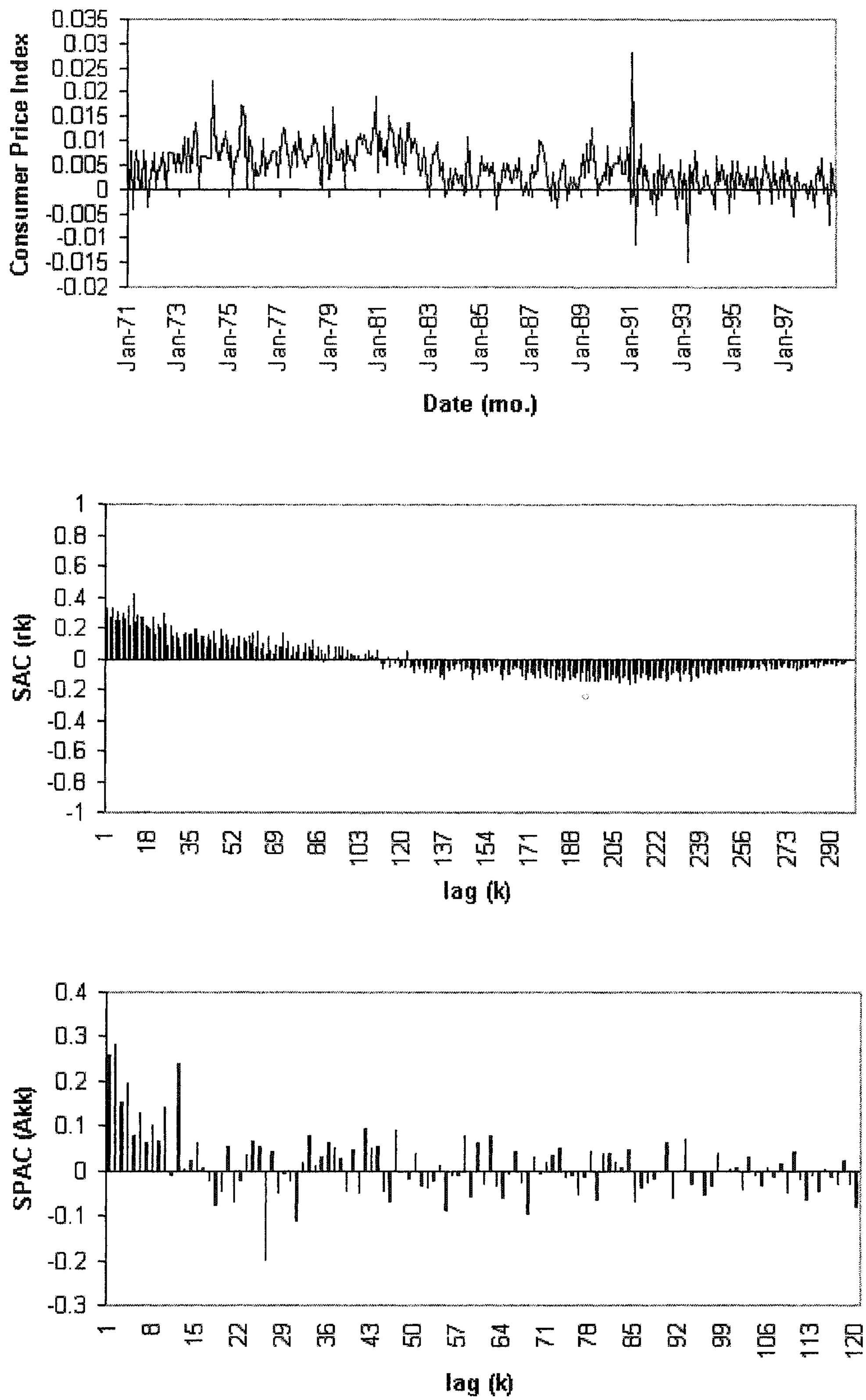


Figure C:2 - Differencing, SACF and SPACF Plots with Regular First Differencing

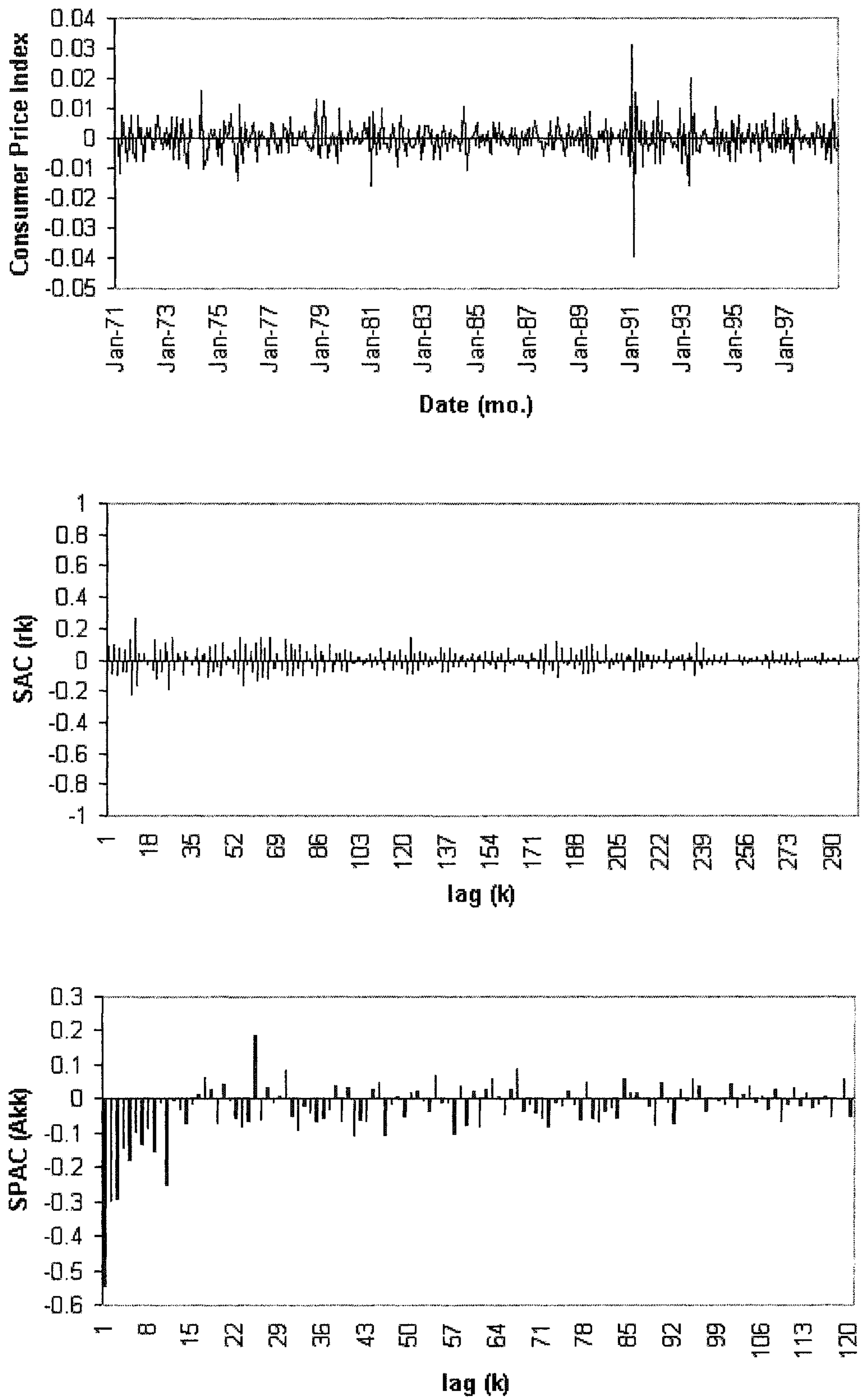


Figure C:3 - Differencing, SACF and SPACF Plots with Regular Second Differencing

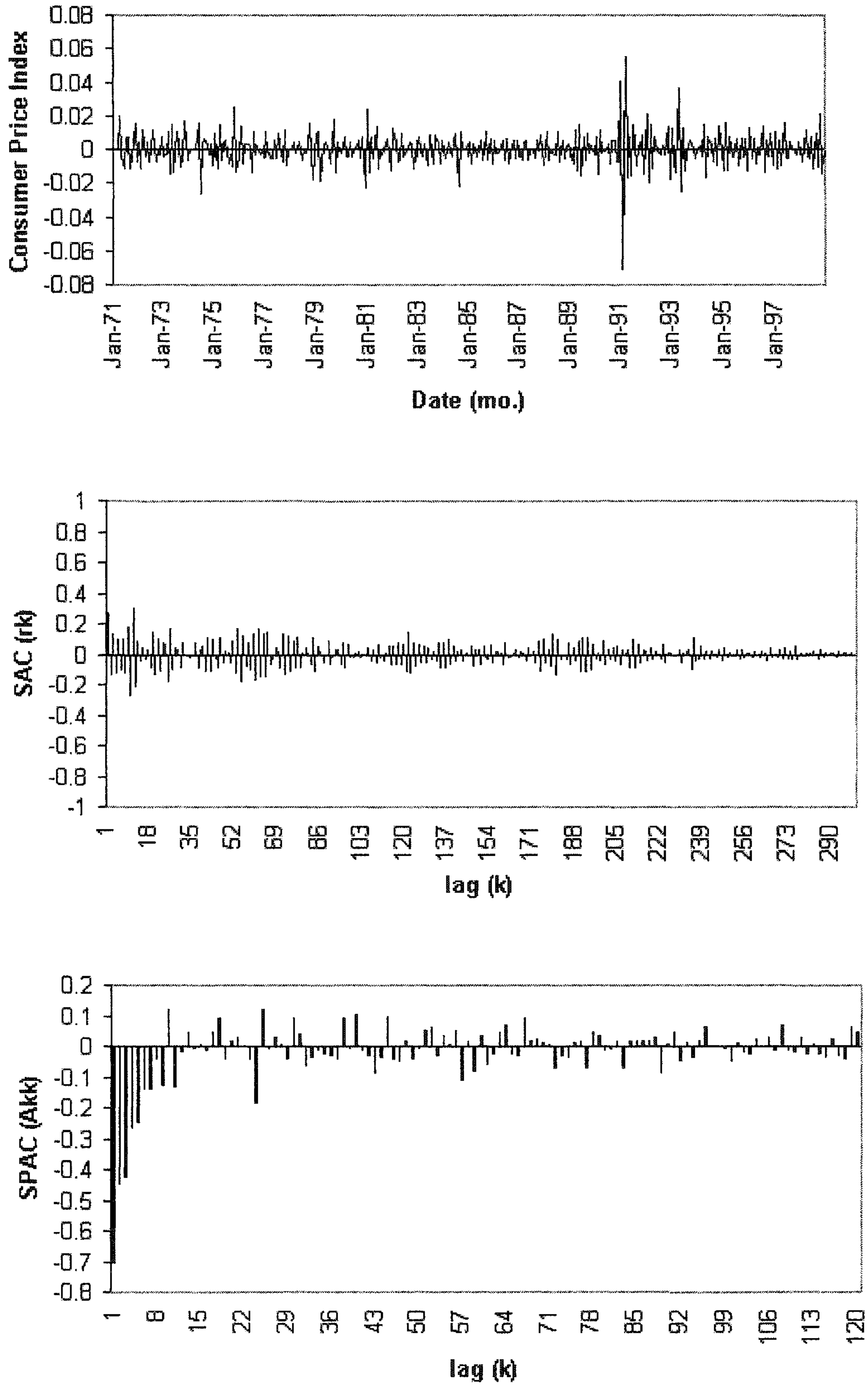


Figure C:4 - Differencing, SACF and SPACF Plots with Regular Third Differencing

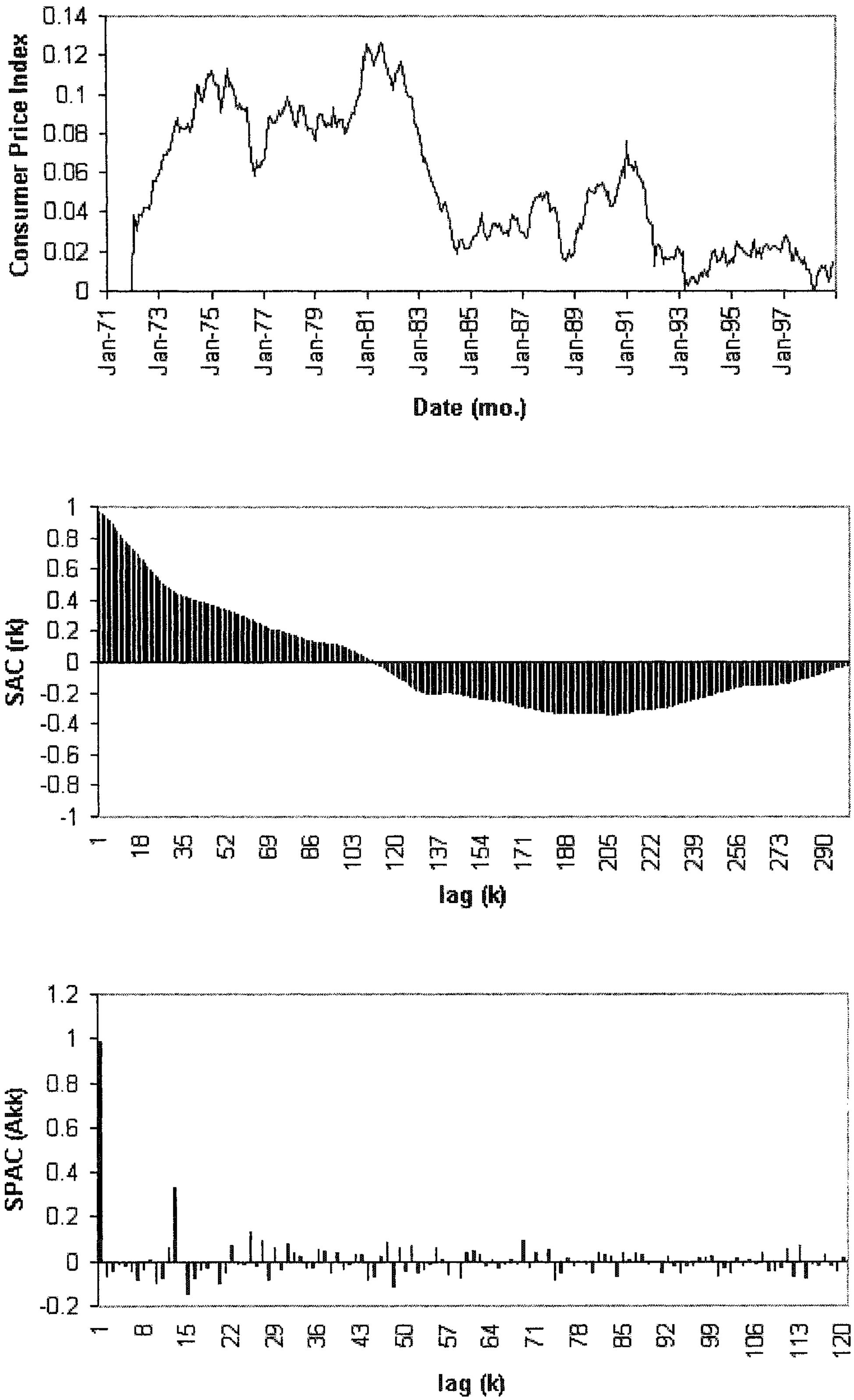


Figure C:5 - Differencing, SACF and SPACF Plots with Seasonal First Differencing

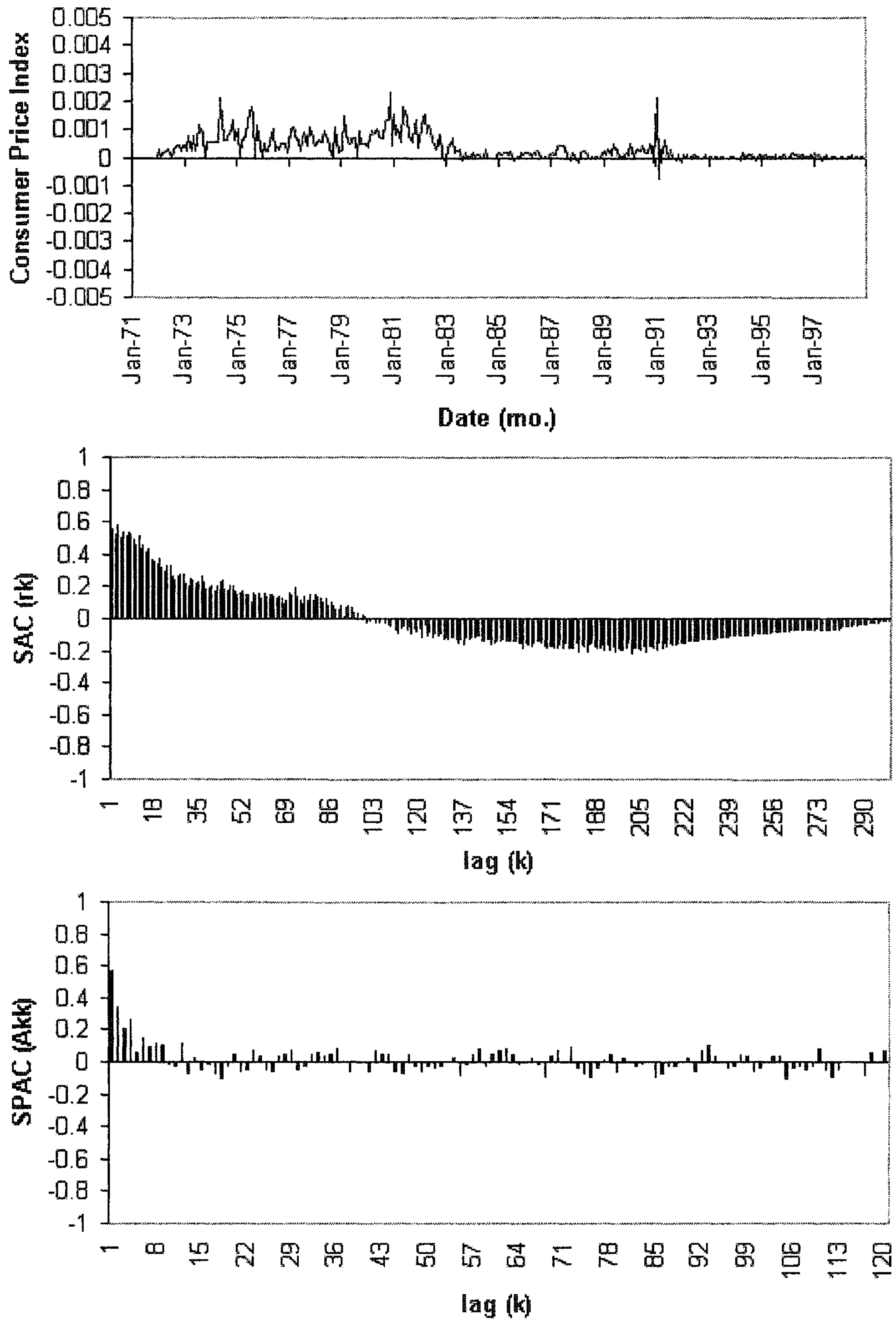


Figure C:6 - Differencing, SACF and SPACF Plots with Regular and Seasonal First Differencing

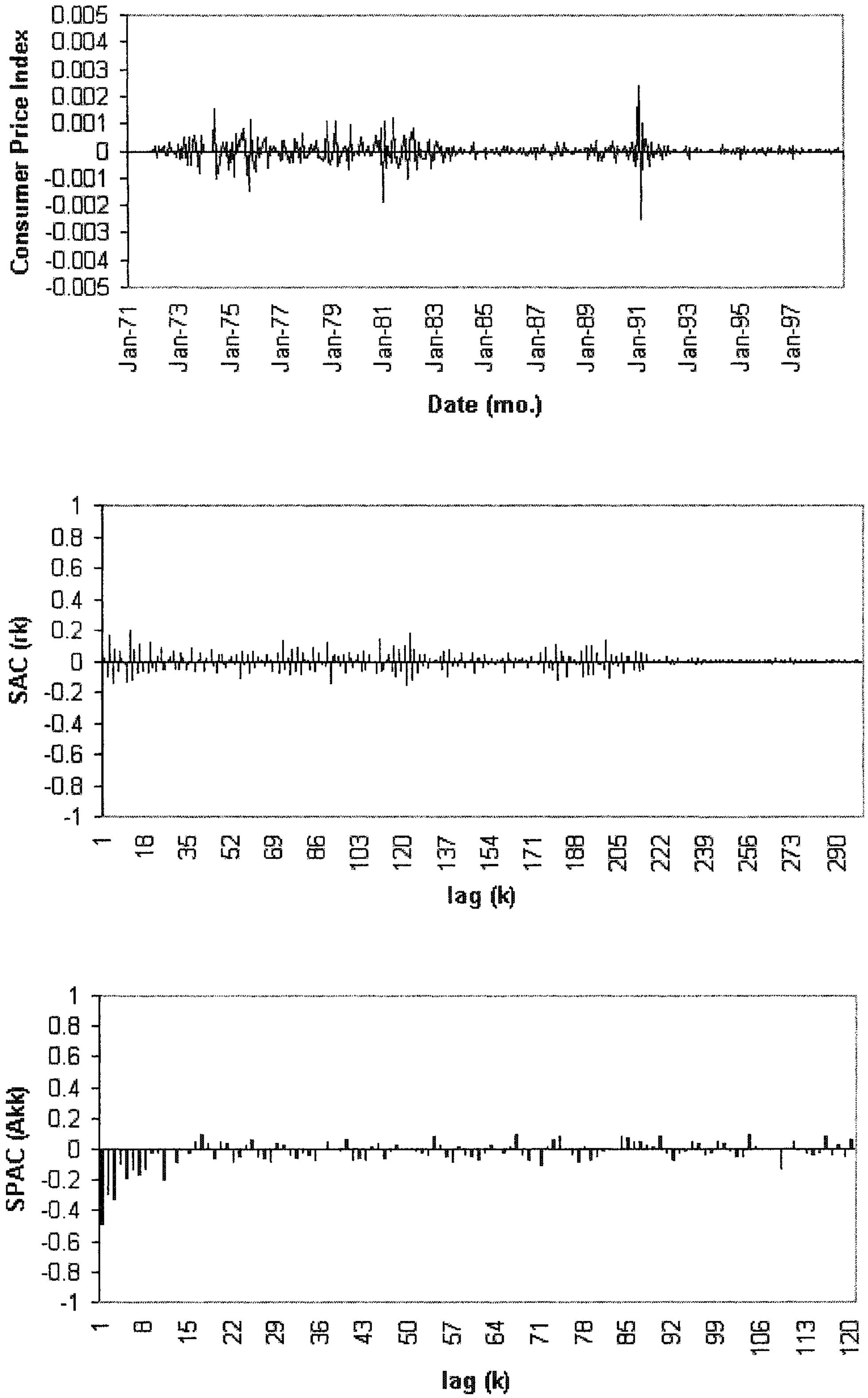


Figure C:7 - Differencing, SACF and SPACF Plots with Regular Second and Seasonal First Differencing

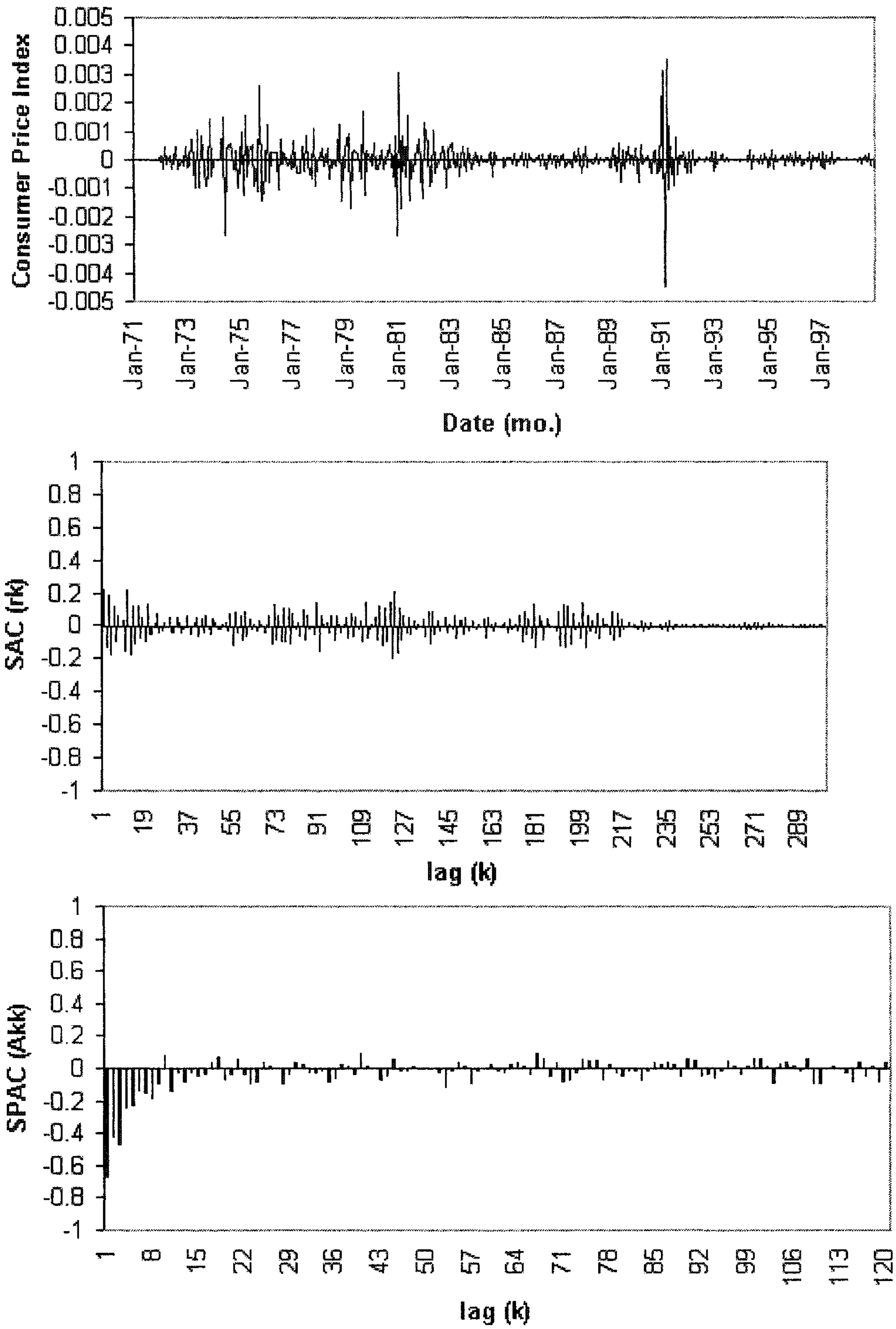


Figure C:8 - Differencing, SACF and SPACF Plots with Regular Third and Seasonal First Differencing

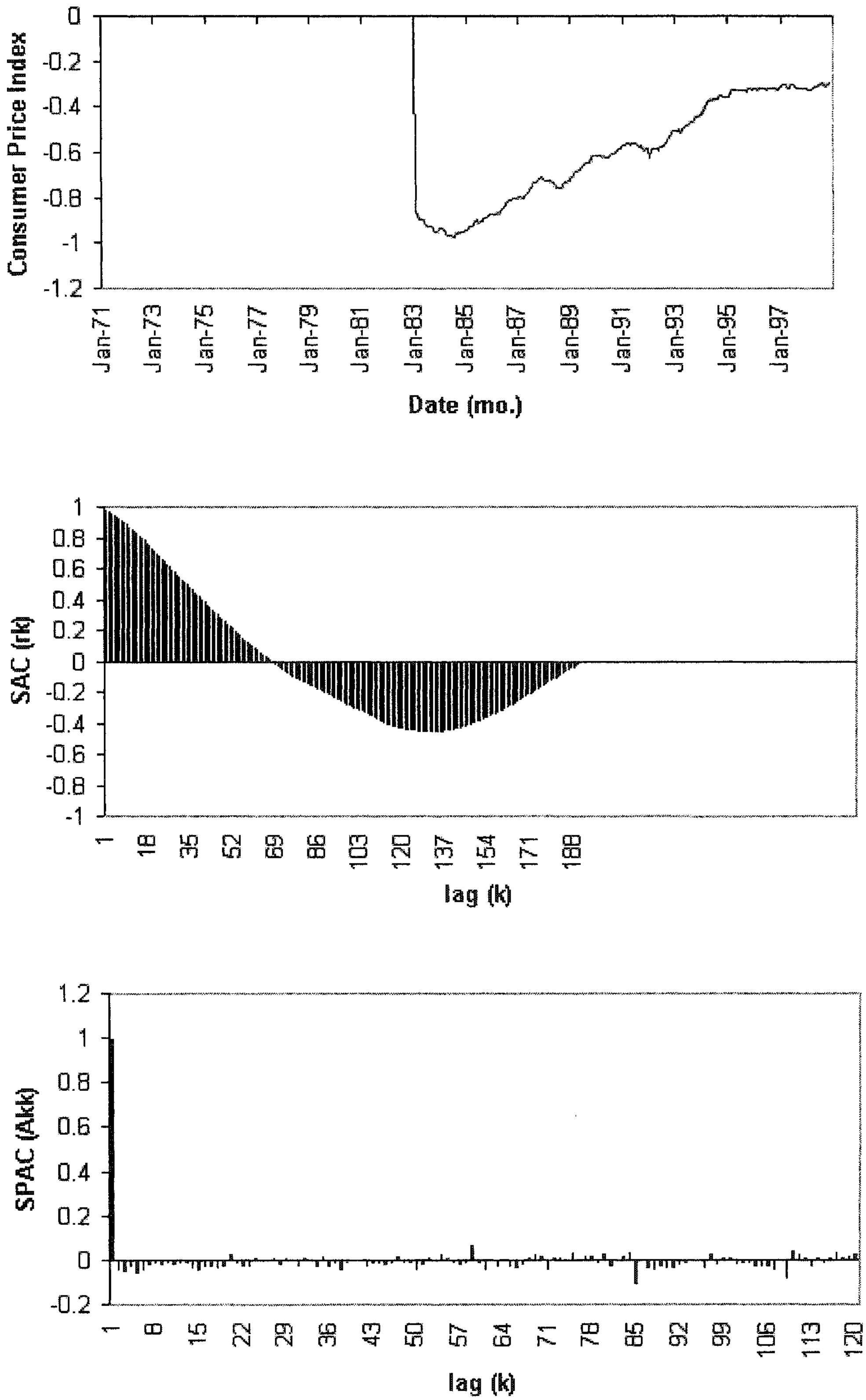


Figure C:9 - Differencing, SACF and SPACF Plots with Seasonal Second Differencing

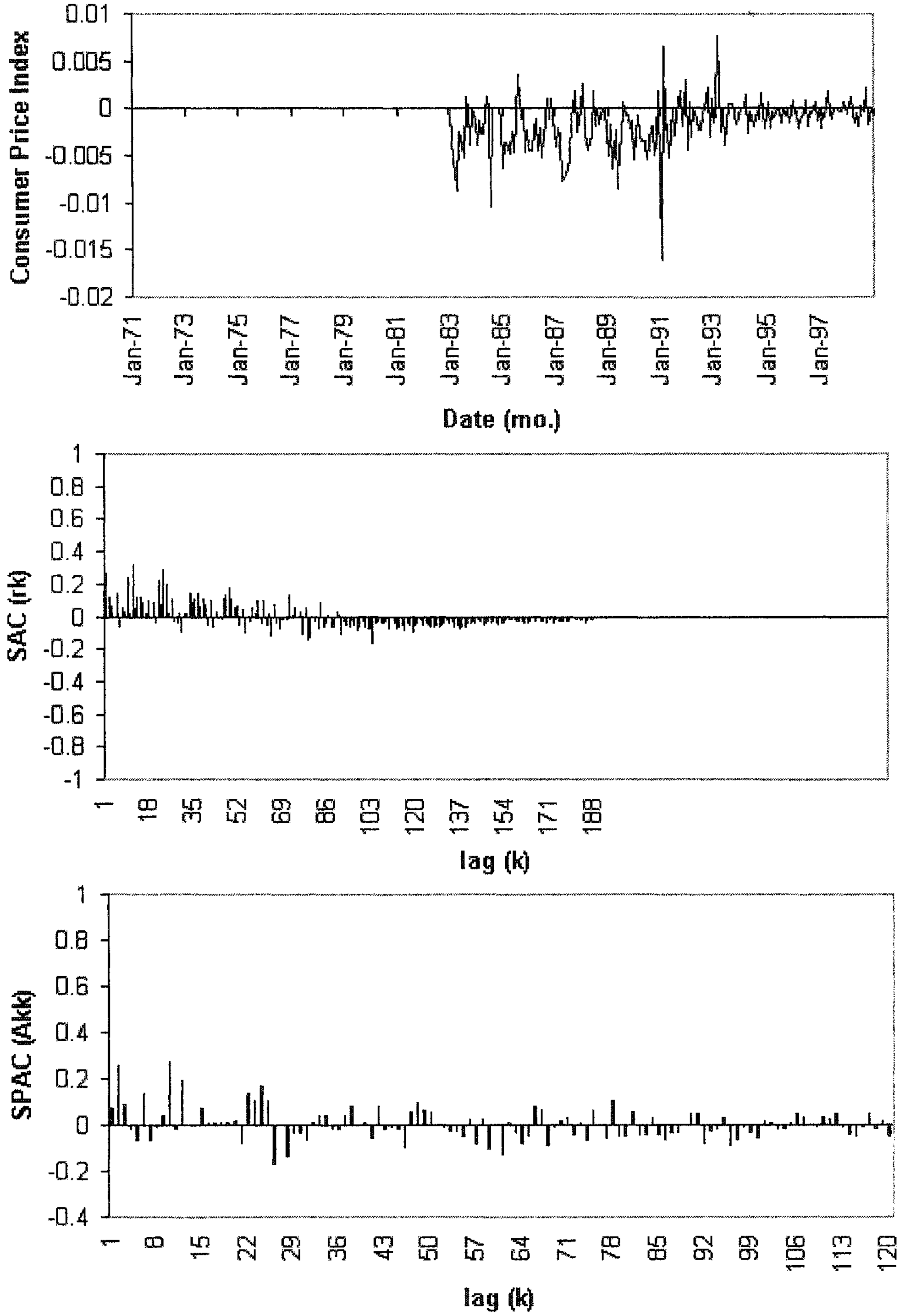


Figure C:10 - Differencing, SACF and SPACF Plots with Regular First and Seasonal Second Differencing

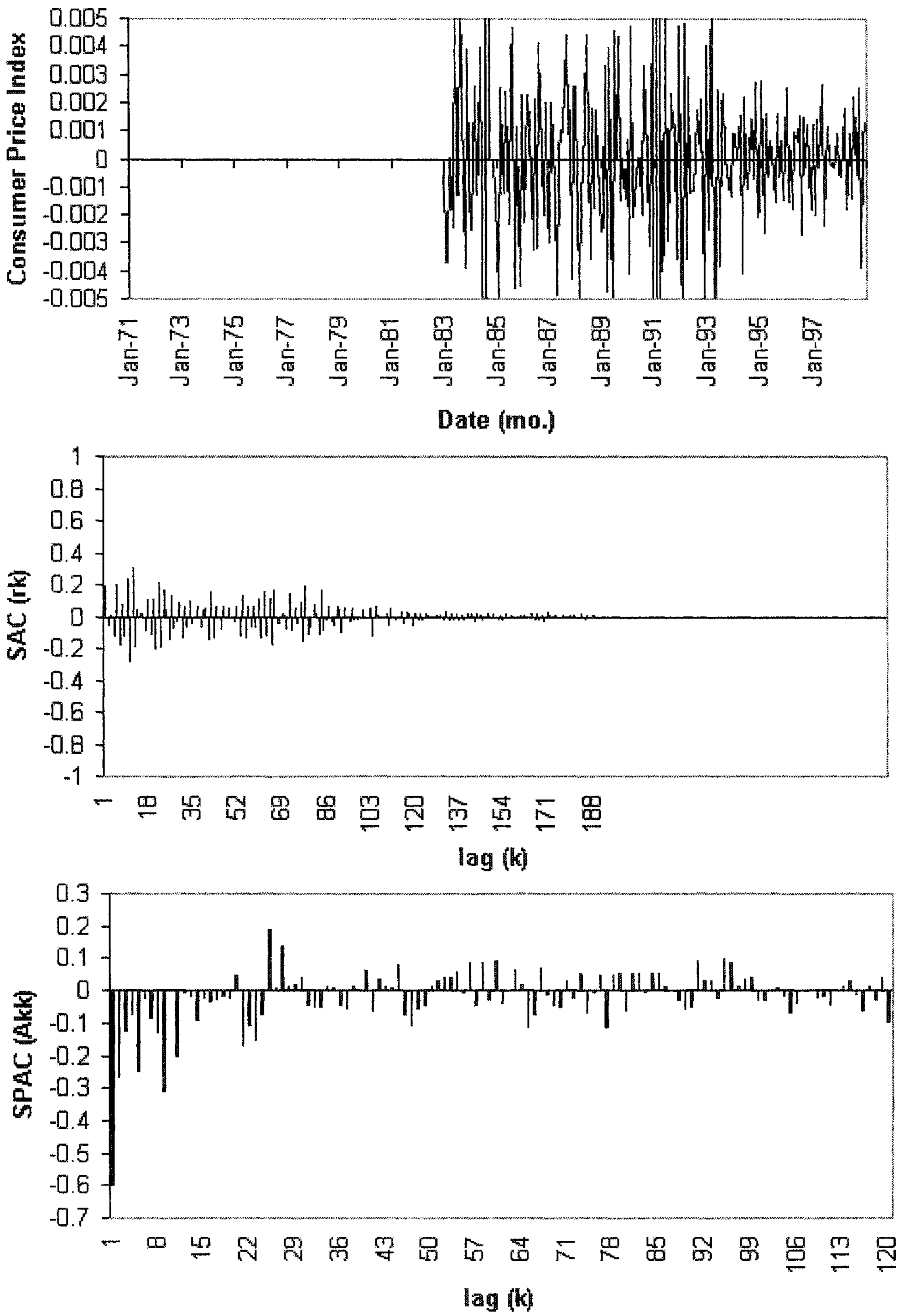


Figure C:11 - Differencing, SACF and SPACF Plots with Regular Second and Seasonal Second Differencing

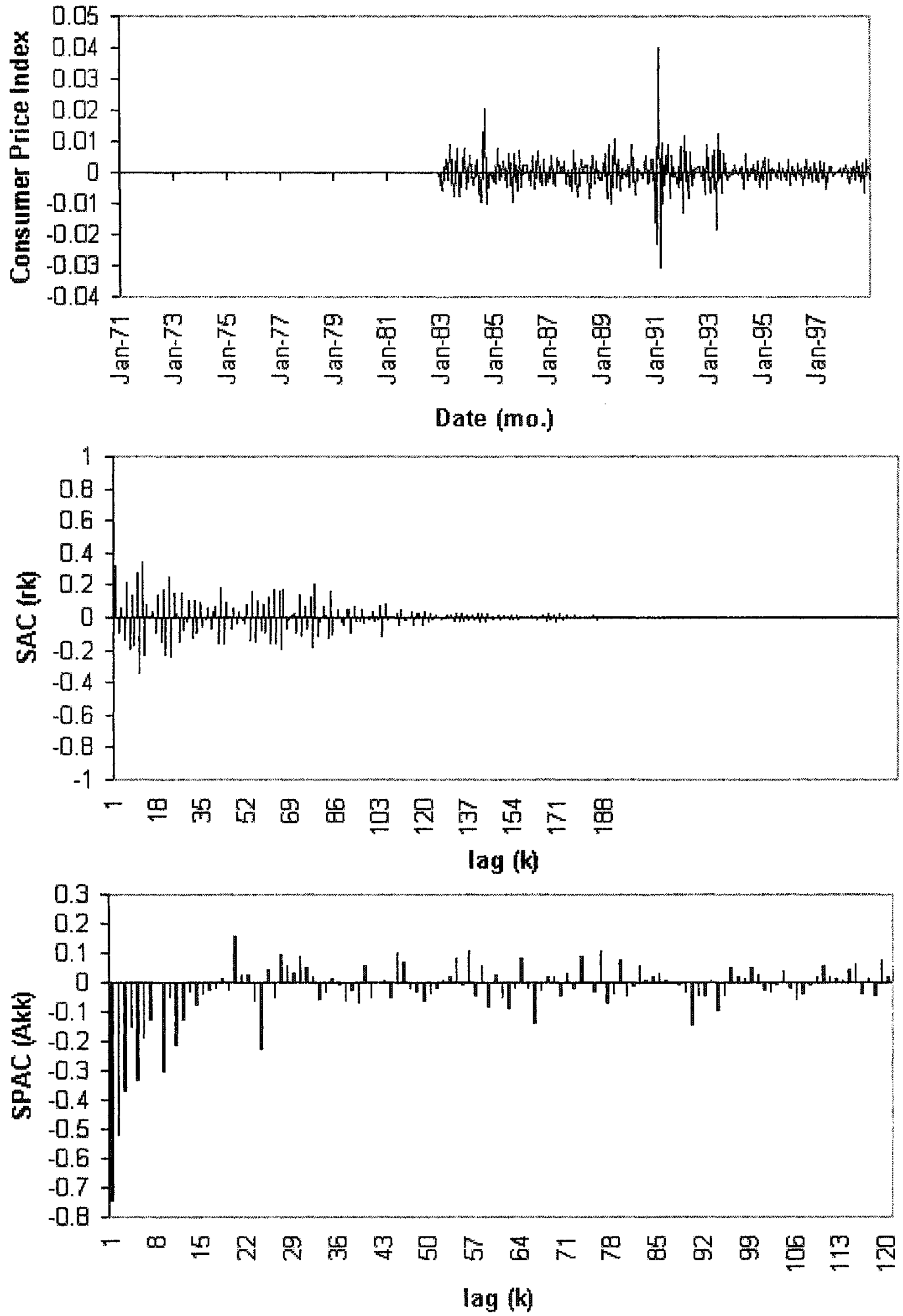


Figure C:12 - Differencing, SACF and SPACF Plots with Regular Third and Seasonal Second Differencing

APPENDIX D: PROJECT PLANNER MANUAL

D.1 OVERVIEW

The Project Planner template is a tool for simulating the overall lifecycle costs of a capital investment project. The template allows the user to incorporate the various project activities with each other using the principles of Critical Path Method (CPM) network scheduling. As well, users can build individual models using the Common template inside each activity element to represent the most detailed processes involved within each activity. In addition to this, the user can input activity duration, indirect costs, and direct costs. For the purpose of incorporating project uncertainty into the model, the user can assign probability distributions to the duration, indirect cost, and direct cost.

By assigning probability distributions to the activity inputs, Simphony can then generate random values for each input. These random inputs, which are based on the assigned distribution, are summed for each user defined time interval, and then multiplied by a forecasted interest rate, which is selected from a database source. By doing this, the current dollar activity cost is transformed into an actual dollar cost. Once this is done, the net present value (NPV) is calculated from all the total actual costs. Simphony collects this NPV value throughout a large number of simulation runs. From the collected NPV values, the minimum, maximum, mean, and standard deviation are calculated, as well as a histogram and CDF graph are produced.

The template provides the user with seven main elements: (1) project planner, which is the highest element in the hierarchy of elements, (2) start element, which represents the start of the project and starts the simulation, (3) collector element, which allow for multiple levels of project process levels, (4) activity element, which has duration and costs associated with them,

(5) input element, which is the start of a detailed activity process within an activity, usually created using the Common template, (6) output element, which is the finish of the detailed activity process within an activity, and (7) the finish element, which represent the finish of the project.

D.2 CREATING A NEW MODEL

To create a new model in the Project Planner template, the following steps can be followed:

1. Create a Project Planner Root element.
2. Define the input parameters of the Project Planner element.
3. Determine the number of collectors required for the project and create these collectors inside the root element and within the collector elements themselves.
4. Create Start and Finish elements inside the root element.
5. Connect the connection points in a manner that properly represents the project CPM schedule.
6. Determine the number of activities required for each collector and create these activities inside the collector elements.
7. Define the input parameters of the activity elements.
8. Connect the connection points of the activity elements in a manner that properly represents the project CPM schedule.

9. If activities are to have sub simulation models within the element, create these models using the Input and Output elements to represent the start and finish of the sub simulation model.

10. Define the number of runs in the project properties dialog box (file menu) and start the simulation.

The following sections describe the details of using each element in the template.

D.3 PROJECT PLANNER ELEMENT

D.3.1 Creating and Connecting:

The project planner element is the root element for the model. This model cannot be created in another planner element. In addition to this, no other elements can be created outside of this element.

D.3.2 Input Parameters:

Discount Rate(%): This number represents the discount rate which is used to discount the accumulated future cash flows in actual dollar amounts.

D.3.3 Output:

None.

D.3.4 Statistics:

Net Present Value: This value represents the total discounted project cost in actual monetary values. This statistic produces a graph, which shows the CDF for the project NPV.

Finish Time: This value represents the project completion time.

D.4 START ELEMENT

D.4.1 Creating and Connecting:

The start element is used only for the purpose of starting the simulation process. This element cannot be created outside of a project planner element. This element must be created at the beginning of the project network.

D.4.2 Input Parameters:

None.

D.4.3 Output:

None.

D.4.4 Statistics:

None.

D.5 FINISH ELEMENT

D.5.1 Creating and Connecting:

The finish element is used for the purpose of determining the finish time of the project. This element cannot be created outside of a project planner element. This element must be created at the end of the project network.

D.5.2 Input Parameters:

None.

D.5.3 Output:

Finish Time: This value represents the finish time of the project.

D.5.4 Statistics:

None.

D.6 COLLECTOR ELEMENT

D.6.1 Creating and Connecting:

The collector element is used so hierarchical detailing can be created amongst the project activities. There can be as many collector element levels as desired by the user. Activities can only be created inside a collector element. For the first collector in a network, no element is required to precede this element, except if a collector is directly under the Project Planner element, then the first collector element must be preceded by a start element. The same is true for the final collector element in a network. Unless the collector element is in the first level under the project planner element, no finish element needs to succeed the last collector element.

D.6.2 Input Parameters:

Collector Description: This input allows the user to input the name of the collector. This name is placed on the collector box.

Overhead: This input allows the user to assign a percentile to the costs in any collector or activity in its child elements. Those costs will be multiplied by this overhead percentage amount.

D.6.3 Output:

None.

D.6.4 Statistics:

None.

D.7 ACTIVITY ELEMENT

D.7.1 Creating and Connecting:

The activity element is used to define the various activities required to complete a project. Activities must be created inside a collector element. Activities can be connected together in a manner of finish-to-start relationships. Like the collector element, there can only be one activity element at the start of the network (this may be a dummy with zero duration). This first activity must not be preceded by any other element. Like wise, only one final activity can be created in the network of activities (this may be a dummy with zero duration). This last activity may not be succeeded by any other element.

D.7.2 Input Parameters:

Model Duration?: The value of this input is selected from a list box with the option of selecting "Yes" or "No". If the user selects "Yes", then the user must create a process simulation model inside the Activity Element's child window. The duration of the activity will be the time taken to complete the simulation of the model developed inside the element. The model inside the Activity Element can be created using other developed templates for Simphony. If the user selects "No", then the user must input a duration value in the "Duration" input parameter in the Activity Element.

Activity Description: This input allows the user to input the name of the activity. This name is placed on the activity box.

Forecast Type: The user must select from the list box the database table that contains the forecast interest or inflation rate relevant to the specific activity. The values in this table will be used to transform the activities current dollar cash flow to actual dollar cash flow. As well, this table must include a mean and standard deviation so that the future interest or inflation rates can be randomly sampled from a normal distribution with parameters that will be defined by the values in the database table.

Activity Duration: This value represents the duration of the specific activity. This value can be assigned a probability distribution to account for uncertainty in the duration time. The units of time used for the activity should remain consistent for all activities.

Activity Direct Cost ($): This value represents the direct cost of the activity. This cost is not associated with time. This value can be assigned a probability distribution to account for direct cost uncertainty.

Activity Indirect Cost ($/time unit): This value represents the indirect cost of the activity per time interval. This value can be assigned a probability distribution to account for indirect cost uncertainty.

D.7.3 Output:

None.

D.7.4 Statistics:

None.

D.8 IN ELEMENT

D.8.1 Creating and Connecting:

The In element can only be created inside an activity element. The In element only has an output connection point, which is connected to the Simphony simulation model of any type (usually the Common Template) to begin that simulation. Only one In element can be created inside an activity element.

D.8.2 Input Parameters:

None.

D.8.3 Output:

None.

D.8.4 Statistics:

None.

D.9 OUT ELEMENT

D.9.1 Creating and Connecting:

The Out element can only be created inside an activity element. The Out element only has an input connection point, which is connected to the Simphony simulation model of any type (usually the Common Template) to mark the finish of that simulation. Only one Out element can be created inside an activity element.

D.9.2 Input Parameters:

None.

D.9.3 Output:

None.

D.9.4 Statistics:

None.

APPENDIX E: SIMPHONY SPS TOOL COMPUTER CODE

E.1 PROJECT PLANNER ELEMENT CODE

```
Option Explicit

Public Function NB_TProjectParent_OnCreate(ob As CFCSim_ModelingElementInstance, x As
Single, y As Single) As Boolean

  If ob.Parent.ElementType="NB_TProjectParent" Then
     MessagePrompt "This element can not be created inside a Project Planner Root element!"
     NB_TProjectParent_OnCreate=False
     Exit Function
  End If

  If ob.Parent.ElementType="NB_TActivity" Then
     MessagePrompt "This element can not be created inside an Activity element!"
     NB_TProjectParent_OnCreate=False
     Exit Function
  End If

  If ob.Parent.ElementType="NB_TCollector" Then
     MessagePrompt "This element can not be created inside a Collector element!"
     NB_TProjectParent_OnCreate=False
     Exit Function
  End If

  NB_TProjectParent_OnCreate=True
  ob.OnCreate x,y,True

  ob.AddAttribute "CashFlow","Cost Spread of Money",CFC_Array,CFC_Single,CFC_Hidden
  ob("CashFlow").SetRC 1,190
  ob.AddAttribute "CalcNPV","Calculate NPV", CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "Counter","Counter",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "Counter2","Counter2",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "Counter3","Counter3",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "Rate","Minimum Acceptable Rate of Return (MARR) or Discount Rate
       (%)",CFC_Numeric,CFC_Single,CFC_ReadWrite
  ob.AddAttribute "FT","FT",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddStatistic "NPV","Actual Net Present Value",False,True
  ob.AddStatistic "FinishTime","Finish Time",False,True
  ob.AddAttribute "SendEnt","Name of Activity of Collector to Send Entity
       To",CFC_Object,CFC_Single,CFC_Hidden

  ob.SetNumCoordinates 2
  ob.CoordinatesX(0)=x
  ob.CoordinatesY(0)=y
  ob.CoordinatesX(1)=x+225
  ob.CoordinatesY(1)=y+157

End Function

Public Sub NB_TProjectParent_OnDraw(ob As CFCSim_ModelingElementInstance)

  CDC.RenderPicture "Planner4.jpg",ob.CoordinatesX(0),ob.CoordinatesY(0),
       ob.CoordinatesX(1)-ob.CoordinatesX(0),ob.CoordinatesY(1)-ob.CoordinatesY(0)
  If ob.Selected Then
     CDC.Rectangle ob.CoordinatesX(0)-2,ob.CoordinatesY(0)-
               2,ob.CoordinatesX(1)+2,ob.CoordinatesY(1)+2
  End If

  ob.DrawConnectionPoints

End Sub

Public Sub NB_TProjectParent_OnSimulationInitializeRun(ob As CFCSim_ModelingElementInstance
,RunNum As Integer)

  ob("Counter")=0
```

```
  ob("Counter2")=0
  ob("CalcNPV")=0
  ob("Counter3")=0
  ob("CashFlow").SetRC 1,190


  '=== SET INITIAL VALUES OF ARRAY EQUAL TO ZERO ===
  Do Until ob("Counter3")=189
     ob("CashFlow").ValueRC(0,ob("Counter3")) = 0
     ob("Counter3")=ob("Counter3")+1
  Loop
  '================================================

End Sub

Public Sub NB_TProjectParent_OnSimulationPostRun(ob As CFCSim_ModelingElementInstance,
RunNum As Integer)

  Do Until ob("Counter")=189
     ob("CalcNPV")= ob("CalcNPV")+((ob("CashFlow").ValueRC(0,ob("Counter2"))
        )*((1+(ob("Rate")/100))^(((ob("Counter2")+1)/-1))))
     ob("Counter")=ob("Counter")+1
     ob("Counter2") = ob("Counter2")+1
  Loop

  ob.stat("NPV").Collect(ob("CalcNPV"))
  ob.stat ("FinishTime").Collect(ob("FT"))

End Sub
```

E.2 START ELEMENT CODE

```
Option Explicit

Public Function NB_TStart_OnCreate(ob As CFCSim_ModelingElementInstance, x As Single, y As
Single) As Boolean

  If ob.Parent.ElementType<>"NB_TProjectParent" Then
     MessagePrompt "This element can only be created inside a Project Planner Root element!"
     NB_TStart_OnCreate=False
     Exit Function
  End If

  'Enforce only one Start Activity is allowed in a project
  Dim element As CFCSim_ModelingElementInstance

  For Each element In ob.Parent.ChildElements
     If element.ElementType="NB_TStart" Then
        MessagePrompt "Only one Start Element is allowed in the project!"
        NB_TStart_OnCreate=False
        Exit Function
     End If
  Next

  NB_TStart_OnCreate=True
  ob.OnCreate x,y,True

  ob.AddAttribute "FinishTime","Activity Finish Time",CFC_Numeric,CFC_Single, CFC_Hidden
  ob.AddAttribute "Entity","Entity to Create",CFC_Numeric,CFC_Single,CFC_Hidden

  ob("Entity")=1

  ob.SetNumCoordinates 2
  ob.CoordinatesX(0)=x
  ob.CoordinatesY(0)=y
  ob.CoordinatesX(1)=x+70
  ob.CoordinatesY(1)=y+50

  ob.AddConnectionPoint "Out",x+75,y+25,COutput,5
```

```
End Function

Public Sub NB_TStart_OnDraw(ob As CFCSim_ModelingElementInstance)

  CDC.ChangeFont "Arial",18,True,False,False,False
  CDC.Rectangle ob.CoordinatesX(0),ob.CoordinatesY(0),ob.CoordinatesX(1), ob.CoordinatesY(1)
  CDC.TextOut ob.CoordinatesX(0)+15,ob.CoordinatesY(0)+10, "Start"
  If ob.Selected Then
     CDC.ChangeLineStyle CFC_DOT,1,RGB(255,0,0)
     CDC.Rectangle ob.CoordinatesX(0)-2,ob.CoordinatesY(0)-2,ob.CoordinatesX(1)+
                2,ob.CoordinatesY(1)+2
  End If
  CDC.ChangeLineStyle CFC_SOLID,1,RGB(0,0,0)

  ob.DrawConnectionPoints

End Sub

Public Sub NB_TStart_OnSimulationInitialize(ob As CFCSim_ModelingElementInstance)

  ob.AddEvent "FireEntity"

End Sub

Public Sub NB_TStart_OnSimulationInitializeRun(ob As CFCSim_ModelingElementInstance, RunNum
As Integer)

  ob("FinishTime")=0
  ob.ScheduleEvent ob.AddEntity,"FireEntity",0

End Sub

Public Sub NB_TStart_OnSimulationProcessEvent(ob As CFCSim_ModelingElementInstance, MyEvent
As String, Entity As CFCSim_Entity)

  Dim newEntity As CFCSim_Entity

  Set newEntity = ob.AddEntity

  ob.TransferOut newEntity

  'Tracer.Trace "Entity: " & newEntity.Id & "  Created","Simulation"

End Sub
```

E.3 FINISH ELEMENT CODE

```
Option Explicit

Public Function NB_TFinish_OnCreate(ob As CFCSim_ModelingElementInstance, x As Single, y As
Single) As Boolean

  If ob.Parent.ElementType<>"NB_TProjectParent" Then
     MessagePrompt "This element can only be created inside a Project Root element!"
     NB_TFinish_OnCreate=False
     Exit Function
  End If

  'Enforce only one Start Activity is allowed in a project
  Dim element As CFCSim_ModelingElementInstance

  For Each element In ob.Parent.ChildElements
     If element.ElementType="NB_TFinish" Then
        MessagePrompt "Only one Finish Element is allowed in the project!"
        NB_TFinish_OnCreate=False
        Exit Function
     End If
  Next

  NB_TFinish_OnCreate=True
```

```
  ob.OnCreate x,y,True

  ob.AddAttribute "FinishTime","Activity Finish Time",CFC_Numeric,CFC_Single, CFC_ReadOnly
  ob.AddAttribute "InCountEnt","Count Incoming Entities",CFC_Numeric,CFC_Single, CFC_Hidden

  ob.SetNumCoordinates 2
  ob.CoordinatesX(0)=x
  ob.CoordinatesY(0)=y
  ob.CoordinatesX(1)=x+70
  ob.CoordinatesY(1)=y+50

  ob.AddConnectionPoint "In",x-5,y+25,CInput,5

End Function

Public Sub NB_TFinish_OnDraw(ob As CFCSim_ModelingElementInstance)

  CDC.ChangeFont "Arial",18,True,False,False,False
  CDC.Rectangle ob.CoordinatesX(0),ob.CoordinatesY(0),ob.CoordinatesX(1), ob.CoordinatesY(1)
  CDC.TextOut ob.CoordinatesX(0)+15,ob.CoordinatesY(0)+10, "Finish"
  If ob.Selected Then
     CDC.ChangeLineStyle CFC_DOT,1,RGB(255,0,0)
     CDC.Rectangle ob.CoordinatesX(0)-2,ob.CoordinatesY(0)-2,ob.CoordinatesX(1)
               +2,ob.CoordinatesY(1)+2
  End If
  CDC.ChangeLineStyle CFC_SOLID,1,RGB(0,0,0)

  ob.DrawConnectionPoints

End Sub

Public Sub NB_TFinish_OnSimulationInitialize(ob As CFCSim_ModelingElementInstance)

  ob.AddEvent "Event1",True
  ob.AddEvent "Event2"

End Sub

Public Sub NB_TFinish_OnSimulationInitializeRun(ob As CFCSim_ModelingElementInstance,
RunNum As Integer)

  ob("InCountEnt") = 0

End Sub

Public Sub NB_TFinish_OnSimulationProcessEvent(ob As CFCSim_ModelingElementInstance,
MyEvent As String, Entity As CFCSim_Entity)

  Select Case MyEvent
     Case "Event1"
        ob("InCountEnt")=ob("InCountEnt")+1
        If ob("InCountEnt")=ob.ConnectionPoints("In").RelationsFrom.Count Then
               ob.ScheduleEvent Entity,"Event2",0
        Else
               ob.DeleteEntity Entity
        End If

     Case "Event2"
        ob("FinishTime")=SimTime
        ob.DeleteEntity Entity
  End Select

  ob.Parent("FT") = ob("FinishTime")

End Sub
```

E.4 COLLECTOR ELEMENT CODE

```
Option Explicit
```

```
Public Function NB_TCollector_OnCreate(ob As CFCSim_ModelingElementInstance, x As Single, y
As Single) As Boolean

  If ob.Parent.ElementType="NB_TActivity" Then
     MessagePrompt "This element must be created inside a Project Root or Collector
        element!"
     NB_TCollector_OnCreate=False
     Exit Function
  End If

  Dim element As CFCSim_ModelingElementInstance

  For Each element In ob.Parent.ChildElements
     If element.ElementType="NB_TActivity" Then
        MessagePrompt "Cannot create a collector if an activity has been created!"
        NB_TCollector_OnCreate=False
        Exit Function
     End If
  Next

  NB_TCollector_OnCreate=True
  ob.OnCreate x,y,True

  ob.AddAttribute "CashFlow","Cost Spread of Money",CFC_Array,CFC_Single,CFC_Hidden
  ob("CashFlow").SetRC 1,190
  ob.AddAttribute "Description","Collector Name",CFC_Text,CFC_Single,CFC_ReadWrite
  ob("Description")="Task"& ob.Id
  ob.AddAttribute "Overhead","Work Package Overhead
      (%)",CFC_Numeric,CFC_Single,CFC_ReadWrite
  ob.AddAttribute "SendEnt","Name of Activity of Collector to Send Entity
      To",CFC_Object,CFC_Single,CFC_Hidden
  ob.AddAttribute "InCountEnt","Counts the number of entities
      in",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "CollectCost","Collect Total Cost",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddStatistic "PackageCost","Work Package Total Actual Cost",False,True
  ob.SetNumCoordinates 2
  ob.CoordinatesX(0)=x
  ob.CoordinatesY(0)=y
  ob.CoordinatesX(1)=x+70
  ob.CoordinatesY(1)=y+50

  ob.AddConnectionPoint "MainIn",x-5,y+25,CInput,5
  ob.AddConnectionPoint "MainOut",x+75,y+25,COutput,5
  ob.AddConnectionPoint "ChildIn",x,y,CInput,0
  ob.AddConnectionPoint "ChildOut",x,y,COutput,0

End Function

Public Sub NB_TCollector_OnDraw(ob As CFCSim_ModelingElementInstance)

  CDC.ChangeFont "Arial",15,True,False,False,False
  CDC.TextOut ob.CoordinatesX(0)+8,ob.CoordinatesY(0)+2,"Collector:"
  CDC.Rectangle ob.CoordinatesX(0),ob.CoordinatesY(0),ob.CoordinatesX(1) ,ob.CoordinatesY(1)
  CDC.ChangeFont "Arial",12,True,False,False,False
  CDC.TextOut ob.CoordinatesX(0)+5,ob.CoordinatesY(0)+22, ob("Description")

  If ob.Selected Then
     CDC.ChangeLineStyle CFC_DOT,1,RGB(255,0,0)
        CDC.Rectangle ob.CoordinatesX(0)-2,ob.CoordinatesY(0)-2,ob.CoordinatesX(1)+2,
        ob.CoordinatesY(1)+2
  End If
  CDC.ChangeLineStyle CFC_SOLID,1,RGB(0,0,0)

  ob.DrawConnectionPoints

End Sub

Public Sub NB_TCollector_OnSimulationInitialize(ob As CFCSim_ModelingElementInstance)

     If ob.ConnectionPoints("MainIn").RelationsFrom.Count = 0 Then
     '====INFORM PARENT OF WHICH ACTIVITY TO SEND AND RECIEVE ENTITY========
```

```
        Set ob.Parent("SendEnt").Reference = ob
    End If

End Sub

Public Sub NB_TCollector_OnSimulationInitializeRun(ob As CFCSim_ModelingElementInstance,
RunNum As Integer)

  ob("InCountEnt")=0
  ob("CollectCost")=0
  ob("CashFlow").SetRC 1,190

  Dim C3 As Integer
  C3=0

  Do Until C3 = 189
     '=== SET INITIAL VALUES OF ARRAY EQUAL TO ZERO ===
     ob("CashFlow").ValueRC(0,C3) = 0
     C3=C3+1
  Loop

End Sub

Public Sub NB_TCollector_OnSimulationPostRun(ob As CFCSim_ModelingElementInstance, RunNum
As Integer)

  Dim j As Integer
  Dim Num2 As Double
  j=0

  Do Until j=189
     Num2 =ob("CashFlow").ValueRC(0,j)*(1+(ob("Overhead")/100))
     ob("CollectCost")=ob("CollectCost") + Num2
     j=j+1
  Loop

  ob.stat("PackageCost").Collect(ob("CollectCost"))

End Sub

Public Sub NB_TCollector_OnSimulationTransferIn(ob As CFCSim_ModelingElementInstance,
Entity As CFCSim_Entity, SrcCp As CFCSim_ConnectionPoint, DstCp As CFCSim_ConnectionPoint)

  Dim i As Integer
  Dim Num As Double

  Num=0

  If DstCp.Name = "MainIn" Then                         '==ENTITY CAME FROM MAIN CP==
     If ob.ConnectionPoints("MainIn").RelationsFrom.Count>0 Then      '==NOT FIRST COLLECTOR
IN LEVEL==
        ob("InCountEnt")=ob("InCountEnt")+1
        If ob("InCountEnt")= ob.ConnectionPoints("MainIn").RelationsFrom.Count Then  '==ALL
PRECEDING ELEMENTS MUST FINISH BEFORE THIS ELEMENT PROCEEDS==
               If ob("SendEnt").Reference.ElementType = "NB_TActivity" Then
                              ob("SendEnt").Reference.OnSimulationTransferIn
                                  ob.CurrentEntity, ob.ConnectionPoints("ChildOut")
                                  ,ob("SendEnt").Reference.ConnectionPoints("In")
               ElseIf ob("SendEnt").Reference.ElementType = "NB_TCollector" Then
                              ob("SendEnt").Reference.OnSimulationTransferIn
                                  ob.CurrentEntity,ob.ConnectionPoints("ChildOut")
                                  ,ob("SendEnt").Reference.ConnectionPoints("MainIn")
               End If
        Else
               ob.DeleteEntity Entity
        End If
     Else                                                      '==FIRST COLLECTOR IN LEVEL==
        If ob("SendEnt").Reference.ElementType = "NB_TActivity" Then
                        ob("SendEnt").Reference.OnSimulationTransferIn
                            ob.CurrentEntity,ob.ConnectionPoints
                            ("ChildOut"),ob("SendEnt").Reference.ConnectionPoints("In")
```

```
        ElseIf ob("SendEnt").Reference.ElementType = "NB_TCollector" Then
                        ob("SendEnt").Reference.OnSimulationTransferIn
                             ob.CurrentEntity,ob.ConnectionPoints
                             ("ChildOut"),ob("SendEnt").Reference.ConnectionPoints("MainIn")
        End If
    End If
 Else                                                  '==ENTITY CAME FROM CHILD==
    If ob.ConnectionPoints("MainOut").RelationsTo.Count = 0 Then     '==LAST COLLECTOR IN
LEVEL==
        If ob.Parent.ElementType="NB_TProjectParent" Then     '==PARENT IS ROOT SO DON'T
TRANSFER ENTITY TO IT==
                  For i=0 To 189
                                  Num=ob("CashFlow").ValueRC(0,i)*(1+(ob("Overhead") /100))
                                  '==MUST ADD A NUMBER AS DOUBLE TO ARRAY==
                                  ob.Parent("CashFlow").ValueRC(0,i)=ob.Parent("CashFlow").Valu
                                  eRC(0,i)+ Num
                  Next i
        Else
                  For i=0 To 189
                            Num=ob("CashFlow").ValueRC(0,i)*(1+(ob("Overhead")/100))
                                  ob.Parent("CashFlow").ValueRC(0,i)=ob.Parent("CashFlow").Valu
                                  eRC(0,i)+ Num
                  Next i
                             ob.Parent.OnSimulationTransferIn ob.CurrentEntity,ob.Connection
                             Points("MainOut"),ob.Parent.ConnectionPoints("ChildIn")
        End If
    Else                                               '==NOT LAST COLLECTOR IN LEVEL==
        For i=0 To 189
                  Num=ob("CashFlow").ValueRC(0,i)*(1+(ob("Overhead")/100))
                            ob.Parent("CashFlow").ValueRC(0,i)=ob.Parent("CashFlow").ValueRC(0,i
                            )+ Num
        Next i
        ob.TransferOut ob.CurrentEntity,ob.ConnectionPoints("MainOut")
    End If
 End If

End Sub
```

E.5 ACTIVITY ELEMENT CODE

```
Option Explicit

Public Function NB_TActivity_OnCreate(ob As CFCSim_ModelingElementInstance, x As Single, y
As Single) As Boolean

  If ob.Parent.ElementType<>"NB_TCollector" Then
     MessagePrompt "This element can only be created inside a Collector element!"
     NB_TActivity_OnCreate=False
     Exit Function
  End If

  Dim element As CFCSim_ModelingElementInstance

  For Each element In ob.Parent.ChildElements
     If element.ElementType="NB_TCollector" Then
        MessagePrompt "Cannot create an activity if a collector has been created!"
        NB_TActivity_OnCreate=False
        Exit Function
     End If
  Next

  NB_TActivity_OnCreate=True
  ob.OnCreate x,y,True

  ob.AddAttribute "FileName", "Data Source", CFC_Text,CFC_Single, CFC_Hidden          '=====
WRITE THE PATH NAME OF THE FORECAST DATABASE TO A HIDDEN ATTRIBUTE=======
  ob("FileName")= SimphonyPath & "\templates\Forecast.mdb"
  ob.AddAttribute "Question", "Model duratioin?",CFC_Text,CFC_ListBox,CFC_ReadWrite
  ob.AddAttribute "ForeType","Forecast Type",CFC_Text,CFC_ListBox,CFC_ReadWrite
  ob.AddAttribute "DurHol","Duration Holder",CFC_Numeric, CFC_Single,CFC_Hidden,0.001
```

```
  ob.AddAttribute "Description","Activity Description",CFC_Text,CFC_Single,CFC_ReadWrite
  ob("Description")="Task"& ob.Id
  ob.AddAttribute "ActDur","Activity Duration",CFC_Distribution,CFC_Single,CFC_ReadWrite
  ob.AddAttribute "Quantity","Activity Quantity",CFC_Distribution,CFC_Single, CFC_ReadWrite
  ob.AddAttribute "UnitCost","Avtivity Unit Cost (Direct)",CFC_Distribution,CFC_Single,
      CFC_ReadWrite
  ob.AddAttribute "DirCost","Activity Direct Cost",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "InCost","Activity Indirect Cost ($/Unit Time)",CFC_Distribution,
      CFC_Single,CFC_ReadWrite
  ob.AddAttribute "SInt","Start Time Interger",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "SFrac","Start Time Fraction",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "MInt","Middle Time Interger",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "FInt","Finish Time Interger",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "FFrac","Finish Time Fraction",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "SCost","Start Time Cost",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "MCost","Middle Time Cost",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "FCost","Finish Time Cost",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "StartTime","Start Time of Activity",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "FinishTime","Finish Time of Activity",CFC_Numeric,CFC_Single, CFC_Hidden
  ob.AddAttribute "InCountEnt","Count Number of Incoming Entities",CFC_Numeric,
      CFC_Single,CFC_Hidden
  ob.AddAttribute "InflArr", "Inflation Storage Array",CFC_Array,CFC_Table,CFC_Hidden
  ob.AddAttribute "InflRate","Inflation Rate",CFC_Distribution,CFC_Single,CFC_Hidden
  ob.AddAttribute "SProdRate", "Product of Start Inflation Rates",CFC_Numeric,CFC_Single,
      CFC_Hidden
  ob.AddAttribute "MProdRate", "Product of Middle Inflation Rates",CFC_Numeric,
      CFC_Single,CFC_Hidden
  ob.AddAttribute "FProdRate", "Product of Finish Inflation Rates",CFC_Numeric,
      CFC_Single,CFC_Hidden
  ob.AddAttribute "SACost", "Actual Start Time Cost",CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "MACost", "Actual Middle Time Cost", CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "FACost", "Actual Finish Time Cost", CFC_Numeric,CFC_Single,CFC_Hidden
  ob.AddAttribute "SendEnt","Send Entity Object",CFC_Object,CFC_Single,CFC_Hidden

  ob.SetNumCoordinates 2
  ob.CoordinatesX(0)=x
  ob.CoordinatesY(0)=y
  ob.CoordinatesX(1)=x+70
  ob.CoordinatesY(1)=y+50

  ob.AddConnectionPoint "In",x-5,y+25,CInput,5
  ob.AddConnectionPoint "Out",x+75,y+25,COutput,5
  ob.AddConnectionPoint "ChildIn",x,y,CInput,0
  ob.AddConnectionPoint "ChildOut",x,y,COutput,0

End Function

Public Sub NB_TActivity_OnDraw(ob As CFCSim_ModelingElementInstance)

  CDC.ChangeFont "Arial",15,True,False,False,False
  CDC.TextOut ob.CoordinatesX(0)+13,ob.CoordinatesY(0)+2,"Activity:"
  CDC.Rectangle ob.CoordinatesX(0),ob.CoordinatesY(0),ob.CoordinatesX(1), ob.CoordinatesY(1)
  CDC.ChangeFont "Arial",12,True,False,False,False
  CDC.TextOut ob.CoordinatesX(0)+5,ob.CoordinatesY(0)+22, ob("Description")

  If ob.Selected Then
     CDC.ChangeLineStyle CFC_DOT,1,RGB(255,0,0)
     CDC.Rectangle ob.CoordinatesX(0)-2,ob.CoordinatesY(0)-2,ob.CoordinatesX(1)+2,
        ob.CoordinatesY(1)+2
  End If

  CDC.ChangeLineStyle CFC_SOLID,1,RGB(0,0,0)
  ob.DrawConnectionPoints

End Sub

Public Sub NB_TActivity_OnListBoxInitialize(ob As CFCSim_ModelingElementInstance, attr As
CFCSim_Attribute, lstList As Object)

  Select Case attr.Name
     Case "ForeType"
```

```
        Dim dbName As String
        Dim dbs As Database
        Dim tbl As TableDef
        dbName =ob("FileName")
        Set dbs = DBEngine.Workspaces(0).OpenDatabase(dbName)

        For Each tbl In dbs.TableDefs          '==== LISTS ALL THE EXISTING TABLES IN THE
FORECAST DATABASE IN THE LIST BOX ===
                If Left(tbl.Name,4) <> "MSys" And Left(tbl.Name,4) <> "USys" Then
                        lstList.additem tbl.Name
                End If
        Next

  End Select

  Select Case attr.Name
     Case "Question"
        lstList.additem "Yes"
        lstList.additem "No"
  End Select

End Sub

Public Sub NB_TActivity_OnListBoxSelectItem(ob As CFCSim_ModelingElementInstance, attr As
CFCSim_Attribute, lstList As Object)

  Select Case attr.Name

     Case "ForeType"
        attr.Value=lstList.text
     Case "Question"
        attr.Value=lstList.text

  End Select

End Sub

Public Sub NB_TActivity_OnSimulationInitialize(ob As CFCSim_ModelingElementInstance)


  Dim dbName As String
  Dim dbs As Database
  Dim myset As Recordset
  Dim value, SQL As String
  Dim r As Integer
  Dim i As Integer

  dbName =ob("FileName")
  Set dbs = DBEngine.Workspaces(0).OpenDatabase(dbName)
  value=ob("foretype")
  r = dbs.TableDefs("" & value & "").RecordCount
  ob("InflArr").SetRC (r,2)

  Set myset = dbs.OpenRecordset ("" & value & "")
  myset.MoveFirst              '====INPUT THE VALUES OF THE FORECASTED DATA INTO THE DEFINED
ARRAY====

  For i=0 To r - 1
     ob("InflArr").ValueRC(i,0)=myset!Mean
     ob("InflArr").ValueRC(i,1)=myset!StdDev
     myset.MoveNext
  Next i

  If ob.ConnectionPoints("In").RelationsFrom.Count = 0 Then    '====INFORM PARENT OF WHICH
ACTIVITY TO SEND AND RECIEVE ENTITY========
     Set ob.Parent("SendEnt").Reference = ob
  Else
  End If

  ob.AddEvent "Event2"
```

```
  ob.AddEvent "Event3"

End Sub

Public Sub NB_TActivity_OnSimulationInitializeRun(ob As CFCSim_ModelingElementInstance,
RunNum As Integer)

  ob("DurHol") = 0
  ob("StartTime")= 0
  ob("SInt") = 0
  ob("SFrac") = 0
  ob("SCost") = 0
  ob("FinishTime") = 0
  ob("FInt") = 0
  ob("FFrac") = 0
  ob("FCost") = 0
  ob("MInt") = 0
  ob("MCost") = 0
  ob("InCountEnt") = 0
  ob("InflRate") = 0
  ob("SProdRate") = 0
  ob("MProdRate") = 0
  ob("FProdRate") = 0
  ob("DirCost")=ob("UnitCost")*ob("Quantity")
  'Must place random sample into "Duration Holder" and make sure this value is >0 so that
    the calc's are not divided by 0.

  ob("DurHol")=ob("ActDur")

  If ob("DurHol")<=0 Then
     ob("DurHol")=.001
  Else
  End If

End Sub

Public Sub NB_TActivity_OnSimulationProcessEvent(ob As CFCSim_ModelingElementInstance,
MyEvent As String, Entity As CFCSim_Entity)

  Dim i As Integer
  Dim x As Double

  Select Case MyEvent

     Case "Event2"

        '====For the first part of the activity================
        ob("SInt") = Int (ob("StartTime"))
        ob("SFrac") = 1 - (ob("StartTime") - ob("SInt"))
        ob("FinishTime") = ob("StartTime")+ob("DurHol")
        ob("FInt") = Int (ob("FinishTime"))
        If ob("SInt")<ob("FInt") Then
     ob("SCost") = (ob("DirCost")*(ob("SFrac")/ob("DurHol")))+ (ob("InCost")*ob("SFrac"))
                        ob("SCost") = (ob("DirCost")*(ob("SFrac")/ob("DurHol")))+(ob
                        ("InCost")*ob("SFrac"))
                For i=1 To ob("SInt")
                        x = 0.0
     x = (Sampler.Normal(ob("InflArr").ValueRC(i,0),
                                ob("InflArr").ValueRC(i,1))/Sampler.Normal(ob("InflArr").Valu
                                eRC(i-1,0),ob("InflArr").ValueRC(i-1,1)))-1
                        If i = 1 Then
                                ob("SProdRate")=(1 + x)
                        Else
                                ob("SProdRate")= ob("SProdRate") * (1 + x)
                        End If
                Next i
        End If
     ob("SACost") = ob("SCost")*ob("SProdRate")ob.Parent("CashFlow")
                .ValueRC(0,ob("SInt"))=ob.Parent("CashFlow").ValueRC(0,ob("SInt"))+
                ob("SACost")
        '====================================================
```

```
        '====For the end part of the activity===============

        ob("FFrac") = ob("FinishTime")-ob("FInt")
    ob("FCost") = ob("DirCost")*(ob("FFrac")/ob("DurHol")))+ (ob("InCost")*ob("FFrac"))
        If ob("FInt")=0 Then
                ob("FProdRate")=1
        Else
                For i=1 To ob("FInt")
                        x = 0.0
    x = (Sampler.Normal(ob("InflArr").ValueRC(i,0),
                                ob("InflArr").ValueRC(i,1))/Sampler.Normal(ob("InflArr").Valu
                                eRC(i-1,0),ob("InflArr").ValueRC(i-1,1)))-1
                        If i = 1 Then
                                ob("FProdRate")=(1 + x)
                        Else
                                ob("FProdRate")= ob("FProdRate") * (1 + x)
                        End If
                Next i
        End If
    ob("FACost") = ob("FCost") * ob("FProdRate")ob.Parent("CashFlow").
                ValueRC(0,ob("FInt"))=ob.Parent("CashFlow").ValueRC(0,ob("FInt"))+
                ob("FACost")
        '============================================================

        '====For the middle of the activity that has complete a's======
        ob("MInt") = ob("StartTime")+ob("SFrac")
        If ob("MInt")<ob("FinishTime")-ob("FFrac") Then
                Do Until ob("MInt")+1>ob("FinishTime")-ob("FFrac")
                        ob("MCost") = (ob("DirCost")/ob("DurHol"))+(ob("InCost"))
                                For i=1 To ob("MInt")
                                        x = 0.0
    x = Sampler.Normal(ob("InflArr").ValueRC(i,0)
                                                ,ob("InflArr").ValueRC(i,1))/Sampler.Normal(o
                                                b("InflArr").ValueRC(i-
                                                1,0),ob("InflArr").ValueRC(i-1,1)))-1
                                                If i = 1 Then
                                                        ob("MProdRate")=(1 + x)
                                                Else
    ob("MProdRate")= ob("MProdRate") * (1 + x)
                                                End If
                                Next i
    ob("MACost") = ob("MCost") *
                                ob("MProdRate")ob.Parent("CashFlow").ValueRC(0,ob("MInt"))=ob
                                .Parent("CashFlow").ValueRC(0,ob("MInt"))+ ob("MACost")
                        ob("MInt")=ob("MInt")+1
                Loop
        End If
        '==================================================================
        If ob("Question") = "Yes" Then
                ob.ScheduleEvent Entity,"Event3",0
        Else
                ob.ScheduleEvent Entity,"Event3",ob("DurHol")
        End If

    Case "Event3"

        If ob.ConnectionPoints("Out").RelationsTo.Count = 0 Then      '==LAST ACTIVITY IN
LEVEL==
    ob.Parent.OnSimulationTransferIn ob.CurrentEntity,ob.Connection
                        Points("Out"),ob.Parent.ConnectionPoints("ChildIn")
        Else
        '===SEND TO NEXT ACTIVITY IN SAME LEVEL
                ob.TransferOut ob.CurrentEntity,ob.ConnectionPoints("Out")
        End If

  End Select

End Sub
```

```
Public Sub NB_TActivity_OnSimulationTransferIn(ob As CFCSim_ModelingElementInstance, Entity
As CFCSim_Entity, SrcCp As CFCSim_ConnectionPoint, DstCp As CFCSim_ConnectionPoint)

  If DstCp.Name = "In" Then
     '==ENTITY CAME FROM MAIN CP==
     If ob.ConnectionPoints("In").RelationsFrom.Count>0 Then
               ob("InCountEnt")=ob("InCountEnt")+1
     If ob("InCountEnt")= ob.ConnectionPoints("In").RelationsFrom.Count Then
                       If ob("Question") = "Yes" Then
                               ob("StartTime")=SimTime
     ob("SendEnt").Reference.OnSimulationTransferIn
                                       ob.CurrentEntity,ob.ConnectionPoints("ChildOut"),ob("
                                       SendEnt").Reference.ConnectionPoints("In")
                       Else
                               ob.ScheduleEvent Entity,"Event2",0
                               ob("StartTime")=SimTime
                       End If
               Else
                       ob.DeleteEntity Entity
               End If
     Else
        If ob("Question") = "Yes" Then
               ob("StartTime")=SimTime
     ob("SendEnt").Reference.OnSimulationTransferIn
                       ob.CurrentEntity,ob.ConnectionPoints("ChildOut"),ob("SendEnt").Refer
                       ence.ConnectionPoints("In")
        Else
               ob.ScheduleEvent Entity,"Event2",0
        End If
     End If
  Else 'Means in came from child
     ob("DurHol")=SimTime-ob("StartTime")
     ob.ScheduleEvent Entity,"Event2",0
  End If

End Sub
```

E.6 IN ELEMENT CODE

```
Option Explicit

Public Function NB_TInput_OnCreate(ob As CFCSim_ModelingElementInstance, x As Single, y As
Single) As Boolean

  If ob.Parent.ElementType<>"NB_TActivity" Then
     MessagePrompt "This element must be created inside an Activity Element!"
     NB_TInput_OnCreate=False
     Exit Function
  End If

  NB_TInput_OnCreate=True

  ob.AddAttribute "Test", "test", CFC_Numeric,CFC_Single,CFC_Hidden


  ob.SetNumCoordinates 2
  ob.CoordinatesX(0)=x
  ob.CoordinatesY(0)=y
  ob.CoordinatesX(1)=x+70
  ob.CoordinatesY(1)=y+50

  ob.AddConnectionPoint "In",x,y,CInput,0
  ob.AddConnectionPoint "Out",x+75,y+25,COutput,5


End Function

Public Sub NB_TInput_OnDraw(ob As CFCSim_ModelingElementInstance)
```

```
  CDC.ChangeFont "Arial",18,True,False,False,False
  CDC.Rectangle ob.CoordinatesX(0),ob.CoordinatesY(0),ob.CoordinatesX(1), ob.CoordinatesY(1)
  CDC.TextOut ob.CoordinatesX(0)+15,ob.CoordinatesY(0)+10, "IN"
  If ob.Selected Then
     CDC.ChangeLineStyle CFC_DOT,1,RGB(255,0,0)
        CDC.Rectangle ob.CoordinatesX(0)-2,ob.CoordinatesY(0)-2,ob.CoordinatesX(1)+2,
        ob.CoordinatesY(1)+2
  End If
  CDC.ChangeLineStyle CFC_SOLID,1,RGB(0,0,0)

  ob.DrawConnectionPoints

End Sub

Public Sub NB_TInput_OnSimulationInitialize(ob As CFCSim_ModelingElementInstance)

  Set ob.Parent("SendEnt").Reference = ob

End Sub

Public Sub NB_TInput_OnSimulationTransferIn(ob As CFCSim_ModelingElementInstance, Entity As
CFCSim_Entity, SrcCp As CFCSim_ConnectionPoint, DstCp As CFCSim_ConnectionPoint)

  ob("Test")=SimTime

  ob.TransferOut ob.CurrentEntity,ob.ConnectionPoints("Out")

End Sub
```

E.7 OUT ELEMENT CODE

```
Option Explicit

Public Function NB_TInput_OnCreate(ob As CFCSim_ModelingElementInstance, x As Single, y As
Single) As Boolean

  If ob.Parent.ElementType<>"NB_TActivity" Then
     MessagePrompt "This element must be created inside an Activity Element!"
     NB_TInput_OnCreate=False
     Exit Function
  End If

  NB_TInput_OnCreate=True

  ob.AddAttribute "Test", "test", CFC_Numeric,CFC_Single,CFC_Hidden


  ob.SetNumCoordinates 2
  ob.CoordinatesX(0)=x
  ob.CoordinatesY(0)=y
  ob.CoordinatesX(1)=x+70
  ob.CoordinatesY(1)=y+50

  ob.AddConnectionPoint "In",x,y,CInput,0
  ob.AddConnectionPoint "Out",x+75,y+25,COutput,5


End Function

Public Sub NB_TInput_OnDraw(ob As CFCSim_ModelingElementInstance)

  CDC.ChangeFont "Arial",18,True,False,False,False
  CDC.Rectangle ob.CoordinatesX(0),ob.CoordinatesY(0),ob.CoordinatesX(1) ,ob.CoordinatesY(1)
  CDC.TextOut ob.CoordinatesX(0)+15,ob.CoordinatesY(0)+10, "IN"
  If ob.Selected Then
     CDC.ChangeLineStyle CFC_DOT,1,RGB(255,0,0)
     CDC.Rectangle ob.CoordinatesX(0)-2,ob.CoordinatesY(0)-2,ob.CoordinatesX(1)+2,
        ob.CoordinatesY(1)+2
  End If
```

```
 CDC.ChangeLineStyle CFC_SOLID,1,RGB(0,0,0)

 ob.DrawConnectionPoints

End Sub

Public Sub NB_TInput_OnSimulationInitialize(ob As CFCSim_ModelingElementInstance)

 Set ob.Parent("SendEnt").Reference = ob

End Sub

Public Sub NB_TInput_OnSimulationTransferIn(ob As CFCSim_ModelingElementInstance, Entity As
CFCSim_Entity, SrcCp As CFCSim_ConnectionPoint, DstCp As CFCSim_ConnectionPoint)
 Tracer.TraceEnabled=True

 ob("Test")=SimTime
 Tracer.Trace "Time at IN = " & ob("Test")

 ob.TransferOut ob.CurrentEntity,ob.ConnectionPoints("Out")

End Sub
```

APPENDIX F: CASE STUDY INPUT DATA

		Quantity			Unit Price					
Work Package	Unit	Min.	Max.	Likely	Min.	Max.	Likely	Overhead (%)	Duration (mo.)	Likely Cost ($)
Land Acquisition										
Land Acquisition	lump sum	1	1	1	$ 7,111,400.00	$ 7,111,400.00	$ 7,111,400.00	20%	15	$ 8,533,680.00
Utility Relocations										
Utility Relocations	lump sum	1	1	1	$ 1,938.00	$ 1,938.00	$ 1,938.00	20%	4.1	$ 2,325.60
Detour Lanes										
Detour Lanes	m2	12200	15250	12200	$ 56.00	$ 56.00	$ 56.00	20%	4.1	$ 819,840.00
New Roadway										
Yellowhead Trail	m2	16940	20328	16940	$ 91.00	$ 98.00	$ 95.00	20%	4.1	$ 1,931,160.00
Ramps & Service Road	m2	17430	20916	17430	$ 56.00	$ 56.00	$ 56.00	20%	4.1	$ 1,171,296.00
156 Street	m2	20570	24684	20570	$ 56.00	$ 56.00	$ 56.00	20%	4.1	$ 1,382,304.00
Local Service Roads	m2	20040	24048	20040	$ 56.00	$ 56.00	$ 56.00	20%	4.1	$ 1,346,688.00
Storm Drainage										
Mobilization	lump sum	1	1	1	$ 100,000.00	$ 100,000.00	$ 100,000.00	0%	4.1	$ 100,000.00
300 0-3	m	56	56	56	$ 171.19	$ 289.61	$ 204.00	0%	4.1	$ 11,424.00
300 0-3	m	240	240	240	$ 171.19	$ 314.81	$ 248.00	0%	4.1	$ 59,520.00
375 0-3	m	90	90	90	$ 183.31	$ 301.49	$ 216.00	0%	4.1	$ 19,440.00
375 0-3	m	242	242	242	$ 183.31	$ 326.69	$ 260.00	0%	4.1	$ 62,920.00
450 0-3	m	275	275	275	$ 202.40	$ 320.40	$ 235.00	0%	4.1	$ 64,683.75
450 0-3	m	115	115	115	$ 202.40	$ 345.60	$ 279.00	0%	4.1	$ 32,085.00
450 3-4	m	120	120	120	$ 237.60	$ 379.20	$ 300.00	0%	4.1	$ 36,000.00
525 0-3	m	467	467	467	$ 220.61	$ 338.19	$ 253.00	0%	4.1	$ 118,113.05
525 0-3	m	230	230	230	$ 220.61	$ 363.39	$ 297.00	0%	4.1	$ 68,310.00
525 5-6	m	31	31	31	$ 295.01	$ 636.99	$ 446.00	0%	4.1	$ 13,826.00
525 6-7	m	237	237	237	$ 375.01	$ 756.99	$ 546.00	0%	4.1	$ 129,292.80
600 0-3	m	90	90	90	$ 243.72	$ 361.08	$ 276.00	0%	4.1	$ 24,840.00
600 0-3	m	160	160	160	$ 243.72	$ 386.28	$ 320.00	0%	4.1	$ 51,200.00
600 3-4	m	120	120	120	$ 278.92	$ 419.88	$ 341.00	0%	4.1	$ 40,920.00
750 0-3	m	70	70	70	$ 316.58	$ 446.22	$ 355.00	0%	4.1	$ 24,850.00
750 0-3	m	129	129	129	$ 316.58	$ 471.42	$ 399.00	0%	4.1	$ 51,307.41

750 3-4	m	150	150	150	$ 351.78	$ 496.62	$ 420.00	0%	4.1	$ 63,000.00
900 0-3	m	96	96	96	$ 441.88	$ 622.52	$ 537.00	0%	4.1	$ 51,552.00
900 3-4	m	140	140	140	$ 475.48	$ 658.52	$ 557.00	0%	4.1	$ 77,980.00
900 4-5	m	13	13	13	$ 491.48	$ 778.52	$ 587.00	0%	4.1	$ 7,631.00
900 5-6	m	100	100	100	$ 515.48	$ 898.52	$ 687.00	0%	4.1	$ 68,700.00
1200 3-4	m	146	146	146	$ 585.96	$ 816.04	$ 661.00	0%	4.1	$ 96,506.00
1200 4-5	m	140	140	140	$ 601.96	$ 936.04	$ 741.00	0%	4.1	$ 103,740.00
1350 4-5	m	91	91	91	$ 701.80	$ 1,036.20	$ 841.00	0%	4.1	$ 76,514.18
1500 3-4	m	129	129	129	$ 825.92	$ 1,081.68	$ 915.00	0%	4.1	$ 118,035.00
1500 4-5	m	242	242	242	$ 841.92	$ 1,201.68	$ 993.00	0%	4.1	$ 240,306.00
Directional Drilling	m	150	150	150	$ 1,000.00	$ 3,000.00	$ 2,000.00	0%	4.1	$ 300,000.00
1200	m (vert.)	84	140	112	$ 920.23	$ 1,191.77	$ 1,056.00	0%	4.1	$ 118,272.00
1500	m (vert.)	22	34	28	$ 1,092.72	$ 1,339.28	$ 1,216.00	0%	4.1	$ 34,048.00
1800	m (vert.)	12	18	15	$ 1,434.29	$ 1,719.71	$ 1,577.00	0%	4.1	$ 23,655.00
2100	m (vert.)	11	13	12	$ 2,234.27	$ 2,735.73	$ 2,485.00	0%	4.1	$ 29,820.00
2400	m (vert.)	28	38	33	$ 2,724.70	$ 3,355.30	$ 3,040.00	0%	4.1	$ 100,320.00
1500 T	m (vert.)	5	7	6	$ 1,581.66	$ 1,594.34	$ 1,588.00	0%	4.1	$ 9,528.00
Catch Basins	ea.	108	108	108	$ 1,800.00	$ 2,833.58	$ 2,400.00	0%	4.1	$ 259,200.00
Catch Basin Leads	m	1350	1350	1350	$ 170.00	$ 219.77	$ 190.00	0%	4.1	$ 256,500.00
Control Structure	ea.	1	1	1	$ 20,000.00	$ 50,000.00	$ 30,000.00	0%	4.1	$ 30,000.00
Inlet (1500 mm)	ea.	2	2	2	$ 4,000.00	$ 6,000.00	$ 5,000.00	0%	4.1	$ 10,000.00
Outlet (525 mm)	ea.	1	1	1	$ 1,500.00	$ 2,500.00	$ 2,000.00	0%	4.1	$ 2,000.00
Connect toExisting Manholes/Pipes	ea.	8	8	8	$ 4,000.00	$ 10,000.00	$ 5,000.00	0%	4.1	$ 40,000.00
Service Connections	ea.	4	4	4	$ 5,000.00	$ 15,000.00	$ 10,000.00	0%	4.1	$ 40,000.00
Wetland Construction	m3	35800	45000	35800	$ 8.00	$ 12.00	$ 10.00	0%	4.1	$ 358,000.00
Ditch Construction	m	200	200	200	$ 50.00	$ 150.00	$ 100.00	0%	4.1	$ 20,000.00
Culvert (1200mm CSP)	m	150	150	150	$ 250.00	$ 450.00	$ 350.00	0%	4.1	$ 52,500.00
Temporary Drainage	ea.	1	1	1	$ 50,000.00	$ 50,000.00	$ 50,000.00	0%	4.1	$ 50,000.00
Adjust Manholes	ea.	15	15	15	$ 1,000.00	$ 2,000.00	$ 1,500.00	0%	4.1	$ 22,500.00
Adjust Catch Basins	ea.	25	25	25	$ 1,500.00	$ 2,000.00	$ 1,720.00	0%	4.1	$ 43,000.00
Fill Placement										
Excavation	m3	84328	105410	84328	$ 10.00	$ 15.00	$ 10.00	20%	7.2	$ 1,011,936.00
Fill	m3	312600	390750	312600	$ 4.00	$ 20.00	$ 5.00	20%	6.2	$ 1,875,600.00

CN Structure										
Mobilization - Walls	lump sum	1	1	-	$ 70,000.00	$ 90,000.00	-	0%	9.8	$ 80,000.00
MSE Walls - S & I	m2	1150	1250	-	$ 325.00	$ 375.00	-	0%	9.8	$ 437,500.00
MSE Walls - granular backfill	m2	1150	1250	-	$ 225.00	$ 275.00	-	0%	9.8	$ 312,500.00
Mobilization - Structure	lump sum	1	1	-	$ 200,000.00	$ 250,000.00	-	0%	9.8	$ 225,000.00
Class SF Concrete	m3	450	500	-	$ 1,125.00	$ 1,275.00	-	0%	9.8	$ 600,000.00
Class B Concrete	m3	475	525	-	$ 825.00	$ 975.00	-	0%	9.8	$ 472,500.00
Pile Concrete	m3	400	700	-	$ 525.00	$ 675.00	-	0%	9.8	$ 420,000.00
PMA	m2	1325	1375	-	$ 20.00	$ 30.00	-	0%	9.8	$ 34,375.00
Girders - Supply, Deliver, Erect	lump sum	1	1	-	$ 700,000.00	$ 850,000.00	-	0%	9.8	$ 775,000.00
Sealer	lump sum	1	1	-	$ 50,000.00	$ 70,000.00	-	0%	9.8	$ 60,000.00
Pedestrian Railing	m	54	56	-	$ 350.00	$ 450.00	-	0%	9.8	$ 22,400.00
Deck Joints	m	72	78	-	$ 1,350.00	$ 1,650.00	-	0%	9.8	$ 117,000.00
YHT Structure										
Mobilization - Walls	lump sum	1	1	-	$ 130,000.00	$ 170,000.00	-	0%	9.8	$ 150,000.00
MSE Walls - S & I	m2	2400	2600	-	$ 325.00	$ 375.00	-	0%	9.8	$ 910,000.00
MSE Walls - granular backfill	m2	2400	2600	-	$ 225.00	$ 275.00	-	0%	9.8	$ 650,000.00
Mobilization - Structure	lump sum	1	1	-	$ 525,000.00	$ 675,000.00	-	0%	9.8	$ 600,000.00
Class SF Concrete	m3	1400	1500	-	$ 1,125.00	$ 1,275.00	-	0%	9.8	$ 1,800,000.00
NU Girders (36 Required)	lump sum	1	1	-	$ 1,050,000.00	$ 1,350,000.00	-	0%	9.8	$ 1,200,000.00
Class B Concrete	m3	1600	1800	-	$ 825.00	$ 975.00	-	0%	9.8	$ 1,620,000.00
Pile Concrete	m3	1200	2000	-	$ 525.00	$ 675.00	-	0%	9.8	$ 1,200,000.00
PMA	m2	3600	3800	-	$ 20.00	$ 30.00	-	0%	9.8	$ 95,000.00
Sealer	lump sum	1	1	-	$ 100,000.00	$ 140,000.00	-	0%	9.8	$ 120,000.00
Deck Joints	m	270	280	-	$ 1,350.00	$ 1,650.00	-	0%	9.8	$ 420,000.00
New Curb & Gutter	m	12650	13915	12650	$ 50.00	$ 71.00	$ 60.00	20%	9.8	$ 910,800.00
1.0m V-Gutter	m	4565	5022	4565	$ 80.00	$ 106.00	$ 90.00	20%	9.8	$ 493,020.00
NJ Barrier 156 Street and Ramps	m	1565	1722	1565	$ 125.00	$ 125.00	$ 125.00	20%	9.8	$ 234,750.00
NJ Barrier Yellowhead Trail	m	1500	1650	1500	$ 125.00	$ 125.00	$ 125.00	20%	9.8	$ 225,000.00
Remove Curb & Gutter	m	3480	4350	3480	$ 8.00	$ 33.00	$ 10.00	20%	9.8	$ 41,760.00
Sidewalk	m2	2183	2401	2183	$ 51.00	$ 75.00	$ 53.00	20%	9.8	$ 138,838.80
Curb Ramps	unit	17	19	17	$ 1,000.00	$ 1,500.00	$ 1,250.00	20%	9.8	$ 25,500.00
Concrete Cap Median 156 Street	m2	3825	4590	3825	$ 80.00	$ 80.00	$ 80.00	20%	9.8	$ 367,200.00

Street Lights/Signals										
Street Lights/Signals	ea.	1	1	1	$ 2,647.00	$ 2,647.00	$ 2,647.00	20%	1.4	$ 3,176.40
Paving Interchange										
50mm Grind	m2	24100	26510	24100	$ 2.00	$ 6.00	$ 3.35	20%	2.4	$ 96,882.00
50mm Overlay	m2	24100	26510	24100	$ 6.00	$ 7.00	$ 6.00	20%	2.4	$ 173,520.00
Slab-on Islands	m2	1035	1139	1035	$ 65.00	$ 103.00	$ 80.00	20%	2.4	$ 99,360.00
Clean & Grubbing	m2	1500	1650	1500	$ 1.00	$ 3.00	$ 3.00	20%	2.4	$ 5,400.00
Remove Detour Road										
Roadway Removal	m2	29200	32120	29200	$ 7.00	$ 12.00	$ 7.00	20%	1	$ 245,280.00
Landscaping										
Naturalized Wetland	m2	27165	30190	28305	$ 0.50	$ 1.00	$ 0.75	0%	16.5	$ 21,228.75
Standard Turf	m2	31365	34135	33140	$ 0.35	$ 1.00	$ 0.50	0%	16.5	$ 16,570.00
150mm Topsoil	m2	87746	87746	87746	$ 0.50	$ 3.00	$ 2.00	0%	16.5	$ 175,492.00
Formal Planting in Beds	m2	4885	8835	7770	$ 20.00	$ 28.00	$ 23.00	0%	16.5	$ 178,710.00
Street Tree Planting	each	253	253	253	$ 475.00	$ 675.00	$ 525.00	0%	16.5	$ 132,825.00
Individual Axial Planting	each	16	16	16	$ 295.00	$ 450.00	$ 350.00	0%	16.5	$ 5,600.00
Naturalized Wetland	m2	5490	5490	5490	$ 8.00	$ 20.00	$ 16.00	0%	16.5	$ 87,840.00
Wetland Fills	m3	21300	21300	21300	$ 3.00	$ 8.00	$ 6.00	0%	16.5	$ 127,800.00
Wetland Soils	m2	31125	31125	31125	$ 3.00	$ 10.00	$ 5.00	0%	16.5	$ 155,625.00
Asphalt Trail	m	545	545	545	$ 65.00	$ 100.00	$ 75.00	0%	16.5	$ 40,875.00
Benches	ea.	4	4	4	$ 750.00	$ 1,500.00	$ 1,000.00	0%	16.5	$ 4,000.00
Picnic Tables	ea.	2	2	2	$ 800.00	$ 2,000.00	$ 1,200.00	0%	16.5	$ 2,400.00
Waste Receptacles	ea.	3	3	3	$ 500.00	$ 1,000.00	$ 750.00	0%	16.5	$ 2,250.00
Traffic Management										
Traffic Management	lump sum	1	1	1	200730	200730	200730	20%	42	$ 240,876.00

Table F:1 - Input Data

APPENDIX G: COMPLETE CASE STUDY SIMULATION RESULTS

Work Package	5 yr. Fixed Cost Estimate	5 yr. Fixed Cost Estimate + 3% Inflation	5 yr. RE + No Inflation			5 yr. RE + Forecasted Inflation		
			Min.	Max.	Mean	Min.	Max.	Mean
Land Acquisition	$ 8,533,680.00	$ 8,728,126.97	$ 8,533,680.00	$ 8,533,680.00	$ 8,533,680.00	$ 8,641,018.69	$ 8,641,018.69	$ 8,641,018.69
Utility Relocations	$ 2,325.60	$ 2,454.24	$ 2,325.60	$ 2,325.60	$ 2,325.60	$ 2,407.67	$ 2,407.67	$ 2,407.67
Detour Lanes	$ 819,840.00	$ 865,189.57	$ 820,001.92	$ 1,018,146.79	$ 896,359.16	$ 849,189.63	$ 1,048,939.62	$ 904,812.98
New Roadway	$ 5,831,448.00	$ 6,154,015.39	$ 5,853,024.00	$ 6,614,717.26	$ 6,215,068.16	$ 6,091,114.11	$ 6,798,289.38	$ 6,412,024.31
Storm Drainage	$ 3,612,039.19	$ 3,806,610.06	$ 3,442,002.13	$ 3,963,609.93	$ 3,697,465.00	$ 3,543,953.79	$ 4,136,893.85	$ 3,823,845.11
Fill Placement	$ 2,887,536.00	$ 3,096,609.21	$ 2,496,620.38	$ 8,016,831.77	$ 4,277,634.77	$ 3,257,497.22	$ 9,516,666.05	$ 5,391,153.82
CN Structure	$ 3,556,275.00	$ 3,747,797.71	$ 3,193,483.73	$ 3,610,901.37	$ 3,374,765.73	$ 3,443,387.89	$ 3,910,161.08	$ 3,635,517.26
YHT Structure	$11,201,868.80	$11,935,219.98	$10,305,969.15	$11,476,754.59	$10,913,811.45	$11,119,257.95	$12,532,172.25	$11,705,536.85
Street Lights/Signals	$ 3,176.40	$ 3,574.16	$ 3,176.40	$ 3,176.40	$ 3,176.40	$ 3,445.75	$ 3,445.75	$ 3,445.75
Paving Interchange	$ 375,162.00	$ 422,635.76	$ 358,075.29	$ 479,802.53	$ 410,578.84	$ 378,646.77	$ 532,787.08	$ 446,252.74
Remove Detour Road	$ 245,280.00	$ 277,464.25	$ 250,829.29	$ 415,643.97	$ 316,581.14	$ 270,015.30	$ 471,927.02	$ 348,410.62
Landscaping	$ 951,215.75	$ 1,022,410.87	$ 811,580.92	$ 1,163,471.81	$ 955,767.08	$ 856,218.55	$ 1,238,551.36	$ 1,009,258.42
Traffic Management	$ 240,876.00	$ 262,732.35	$ 240,876.00	$ 240,876.00	$ 240,876.00	$ 255,152.32	$ 255,152.32	$ 255,152.32
Total Project Cost	$38,260,722.74	$40,324,840.54	$37,570,792.73	$43,339,701.93	$39,838,089.33	$39,840,556.08	$46,569,149.82	$42,578,836.54

Table G:1 - Simulation Results for All Developed Models

	5 yr. RE + 3% Inflation			15 yr. RE + Forecasted Inflation			15 yr. RE + 3% Inflation		
Work Package	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Land Acquisition	$ 8,728,126.97	$ 8,728,126.97	$ 8,728,126.97	$ 10,429,176.00	$ 10,429,176.00	$ 10,429,176.00	$ 11,429,684.30	$ 11,429,684.30	$ 11,429,684.30
Utility Relocations	$ 2,454.24	$ 2,454.24	$ 2,454.24	$ 2,906.02	$ 2,906.02	$ 2,906.02	$ 3,213.89	$ 3,213.89	$ 3,213.89
Detour Lanes	$ 865,624.26	$ 1,074,860.66	$ 945,389.56	$ 1,024,658.41	$ 1,272,256.37	$ 1,122,916.99	$ 1,133,555.00	$ 1,407,554.92	$ 1,240,402.05
New Roadway	$ 6,242,801.74	$ 7,033,290.36	$ 6,565,788.42	$ 7,334,541.30	$ 8,308,060.49	$ 7,787,411.98	$ 8,175,093.39	$ 9,210,256.53	$ 8,596,883.59
Storm Drainage	$ 3,602,231.90	$ 4,209,975.47	$ 3,891,688.72	$ 4,254,192.36	$ 4,942,067.90	$ 4,610,990.48	$ 4,717,206.07	$ 5,513,060.34	$ 5,097,794.14
Fill Placement	$ 3,733,657.44	$ 9,060,898.86	$ 5,425,960.53	$ 4,237,953.43	$ 10,921,860.35	$ 6,606,391.97	$ 4,889,310.85	$ 11,865,456.79	$ 7,028,727.97
CN Structure	$ 3,495,198.52	$ 3,968,426.14	$ 3,765,093.42	$ 4,122,408.95	$ 4,609,900.25	$ 4,355,306.43	$ 4,577,043.37	$ 5,196,745.89	$ 4,929,017.02
YHT Structure	$11,362,930.19	$12,642,846.69	$12,062,921.45	$ 13,485,825.64	$ 14,867,520.79	$ 14,151,983.99	$ 14,880,020.11	$ 16,556,100.39	$ 15,802,506.06
Street Lights/Signals	$ 3,574.15	$ 3,574.15	$ 3,574.15	$ 4,159.40	$ 4,159.40	$ 4,159.40	$ 4,680.45	$ 4,680.45	$ 4,680.45
Paving Interchange	$ 388,408.03	$ 560,031.67	$ 462,682.11	$ 461,789.05	$ 630,211.75	$ 544,406.49	$ 508,629.30	$ 733,374.44	$ 606,484.22
Remove Detour Road	$ 287,070.42	$ 484,201.25	$ 353,769.10	$ 325,340.56	$ 574,165.53	$ 411,859.82	$ 375,926.29	$ 634,074.32	$ 463,236.72
Landscaping	$ 869,011.22	$ 1,286,239.66	$ 1,037,879.19	$ 1,005,676.40	$ 1,416,227.39	$ 1,206,193.54	$ 1,137,990.31	$ 1,684,360.61	$ 1,357,614.03
Traffic Management	$ 262,732.35	$ 262,732.35	$ 262,732.35	$ 307,990.58	$ 307,990.58	$ 307,990.58	$ 344,054.10	$ 344,054.10	$ 344,054.10
Total Project Cost	$41,808,639.42	$46,834,072.73	$43,508,060.22	$ 48,453,173.54	$ 55,136,091.31	$ 51,541,693.68	$ 54,749,382.23	$ 61,330,303.52	$ 56,904,298.52

Table G:1 - Simulation Results for All Developed Models Continued

APPENDIX H: TOTAL PROJECT COST CDF'S FOR SIMULATION MODELS

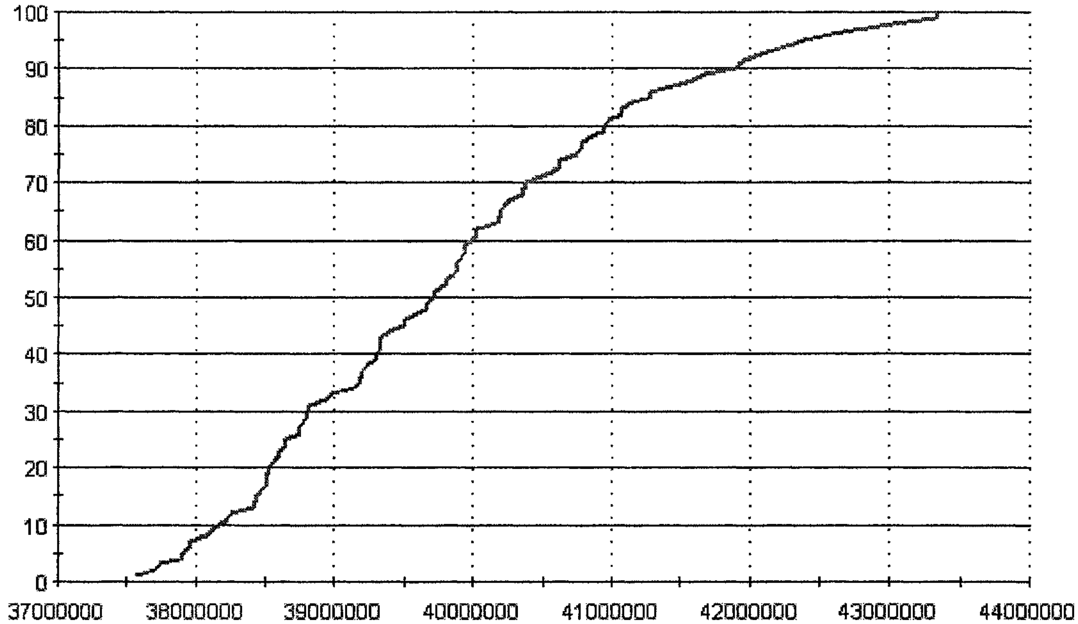


Figure H:1 - Total Project Cost CDF for Range Estimate without Inflation

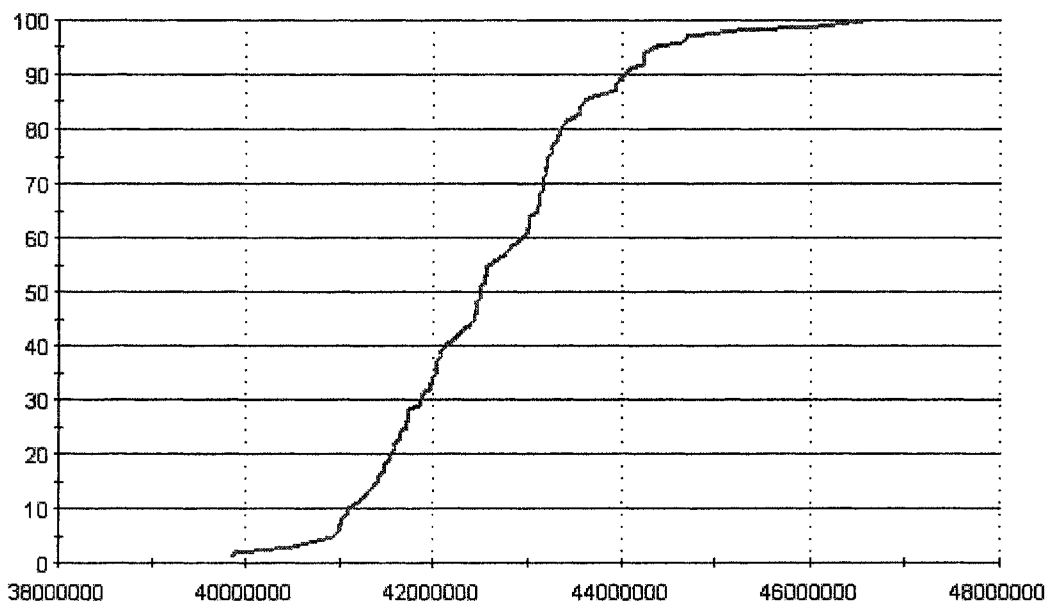


Figure H:2 - Total Project Cost CDF for Range Estimate with Forecasted Inflation

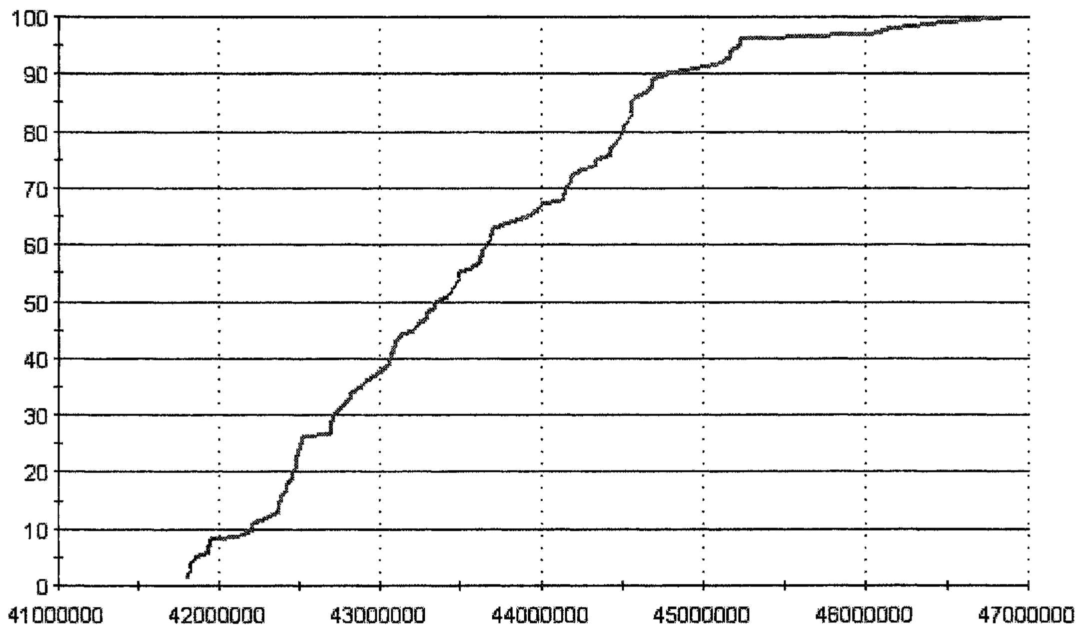


Figure H:3 - Total Project Cost CDF for Range Estimate with 3% Inflation

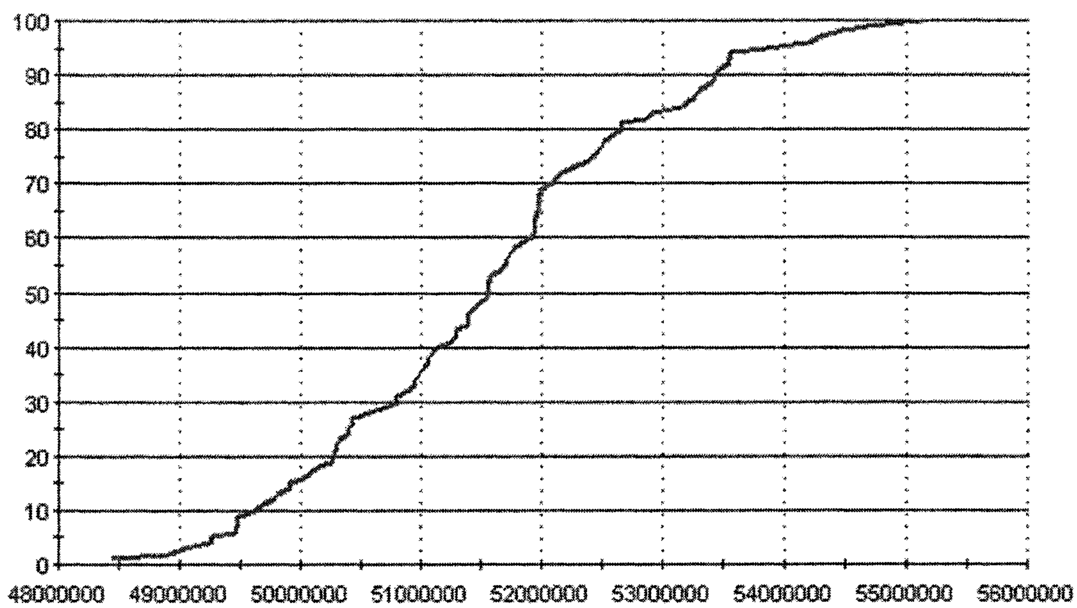


Figure H:4 - Total Project Cost CDF for 15 year Range Estimate with Forecast Inflation

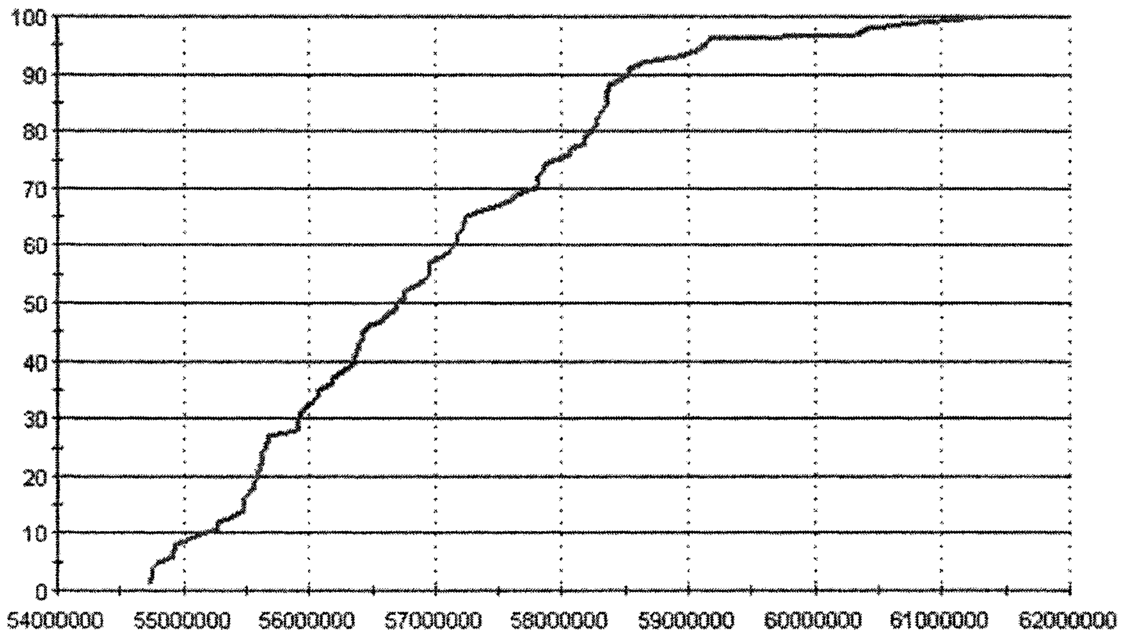


Figure H:5 - Total Project Cost CDF for 15 year Range Estimate with 3% Inflation

APPENDIX I: COST RATIOS FOR PROJECT ACTIVITIES

Work Package	Likely Cost ($)	Cost Ratio (%)
Land Acquisition	$ 8,533,680.00	22.30%
Yellowhead Trail	$ 1,931,160.00	27.35%
Fill	$ 1,875,600.00	32.25%
Class SF Concrete	$ 1,800,000.00	36.96%
Class B Concrete	$ 1,620,000.00	41.19%
156 Street	$ 1,382,304.00	44.81%
Local Service Roads	$ 1,346,688.00	48.32%
NU Girders (36 Required)	$ 1,200,000.00	51.46%
Pile Concrete	$ 1,200,000.00	54.60%
Ramps & Service Road	$ 1,171,296.00	57.66%
Excavation	$ 1,011,936.00	60.30%
New Curb & Gutter	$ 910,800.00	62.68%
MSE Walls - Supply and installation	$ 910,000.00	65.06%
Detour Lanes	$ 819,840.00	67.21%
Girders - Supply, Deliver, Erect	$ 775,000.00	69.23%
MSE Walls - granular backfill and incidental work	$ 650,000.00	70.93%
Class SF Concrete	$ 600,000.00	72.50%
Mobilization - Structure	$ 600,000.00	74.07%
1.0m V-Gutter	$ 493,020.00	75.35%
Class B Concrete	$ 472,500.00	76.59%
MSE Walls - Supply and installation	$ 437,500.00	77.73%
Pile Concrete	$ 420,000.00	78.83%
Deck Joints	$ 420,000.00	79.93%
Concrete Cap Median 156 Street	$ 367,200.00	80.89%
Wetland Construction	$ 358,000.00	81.82%
MSE Walls - granular backfill and incidental work	$ 312,500.00	82.64%
Directional Drilling	$ 300,000.00	83.43%
Catch Basins	$ 259,200.00	84.10%
Catch Basin Leads	$ 256,500.00	84.77%
Roadway Removal	$ 245,280.00	85.41%
Traffic Management	$ 240,876.00	86.04%
1500 4-5	$ 240,306.00	86.67%
New Jersey Barrier 156 Street and Ramps	$ 234,750.00	87.29%
Mobilization - Structure	$ 225,000.00	87.87%
New Jersey Barrier Yellowhead Trail	$ 225,000.00	88.46%
Formal Planting in Beds	$ 178,710.00	88.93%
150mm Topsoil	$ 175,492.00	89.39%
50mm Overlay	$ 173,520.00	89.84%
Wetland Soils	$ 155,625.00	90.25%
Mobilization - Walls	$ 150,000.00	90.64%
Sidewalk	$ 138,838.80	91.00%
Street Tree Planting	$ 132,825.00	91.35%
525 6-7	$ 129,292.80	91.69%
Wetland Fills	$ 127,800.00	92.02%
Sealer	$ 120,000.00	92.34%
1200	$ 118,272.00	92.64%

525 0-3	$	118,113.05	92.95%
1500 3-4	$	118,035.00	93.26%
Deck Joints	$	117,000.00	93.57%
1200 4-5	$	103,740.00	93.84%
2400	$	100,320.00	94.10%
Mobilization	$	100,000.00	94.36%
Slab-on Islands	$	99,360.00	94.62%
50mm Grind	$	96,882.00	94.87%
1200 3-4	$	96,506.00	95.13%
PMA	$	95,000.00	95.38%
Naturalized Wetland	$	87,840.00	95.60%
Mobilization - Walls	$	80,000.00	95.81%
900 3-4	$	77,980.00	96.02%
1350 4-5	$	76,514.18	96.22%
900 5-6	$	68,700.00	96.40%
525 0-3	$	68,310.00	96.58%
450 0-3	$	64,683.75	96.74%
750 3-4	$	63,000.00	96.91%
375 0-3	$	62,920.00	97.07%
Sealer	$	60,000.00	97.23%
300 0-3	$	59,520.00	97.39%
Culvert (1200mm CSP)	$	52,500.00	97.52%
900 0-3	$	51,552.00	97.66%
750 0-3	$	51,307.41	97.79%
600 0-3	$	51,200.00	97.93%
Temporary Drainage	$	50,000.00	98.06%
Adjust Catch Basins	$	43,000.00	98.17%
Remove Curb & Gutter	$	41,760.00	98.28%
600 3-4	$	40,920.00	98.39%
Asphalt Trail	$	40,875.00	98.49%
Connect to Existing Manholes/Pipes	$	40,000.00	98.60%
Service Connections	$	40,000.00	98.70%
450 3-4	$	36,000.00	98.80%
PMA	$	34,375.00	98.89%
1500	$	34,048.00	98.97%
450 0-3	$	32,085.00	99.06%
Control Structure	$	30,000.00	99.14%
2100	$	29,820.00	99.21%
Curb Ramps	$	25,500.00	99.28%
750 0-3	$	24,850.00	99.35%
600 0-3	$	24,840.00	99.41%
1800	$	23,655.00	99.47%
Adjust Manholes	$	22,500.00	99.53%
Pedestrian Railing	$	22,400.00	99.59%
Naturalized Wetland	$	21,228.75	99.65%
Ditch Construction	$	20,000.00	99.70%
375 0-3	$	19,440.00	99.75%
Standard Turf	$	16,570.00	99.79%
525 5-6	$	13,826.00	99.83%
300 0-3	$	11,424.00	99.86%

Inlet (1500 mm)	$	10,000.00	99.88%
1500 T	$	9,528.00	99.91%
900 4-5	$	7,631.00	99.93%
Individual Axial Planting	$	5,600.00	99.94%
Clean & Grubbing	$	5,400.00	99.96%
Benches	$	4,000.00	99.97%
Street Lights/Signals	$	3,176.40	99.98%
Picnic Tables	$	2,400.00	99.98%
Utility Relocations	$	2,325.60	99.99%
Waste Receptacles	$	2,250.00	99.99%
Outlet (525 mm)	$	2,000.00	100.00%

Table I:1 - Cost Ratios for Project Activities