AN INTEGRATED CAD AND SIMULATION MODEL FOR CONCRETE OPERATIONS

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ABSTRACT

Pouring a concrete raft slab is a classic problem in downtown projects because it requires special arrangements to be made with city authorities to close the area around the project during the operation. City authorities allow this only during the weekends that puts a lot of pressure on construction staff to finish pouring the concrete in a limited amount of time. In this paper, a simulation model for predicating the pouring time is introduced. This integrated model consists of: Special Purpose Simulation (Simphony), Microsoft Access, Visual Basic for Application (VBA) and AutoCAD software. Moreover, in this paper the sensitive parameters are analyzed and recommendations for choosing pouring concrete sub-contractors are provided. Additionally the proposed model is applied to a practical case for defining the required time for pouring a lower raft slab for "The Bow" project in downtown Calgary.

1 INTRODUCTION

Concrete raft slab is a basic concrete foundation of any construction building. This paper addresses the problem of pouring concrete for raft slab in down town projects. Pouring concrete for raft slab in downtown projects is always a critical issue because of the necessity to close the area around the project site which is only possible on weekends. The duration of such a concrete pouring operation depends upon the following factors:

- Number of concrete trucks;
- concrete truck's capacity;
- truck's speed (emptying and loading);
- number of batch plants available;
- batch plant production rate;
- distance between the construction site and the concrete batch plant;
- number of concrete pumps;

- concrete pump's production rate.

The objective of this study is to develop a computer model for determining the required time for pouring concrete of raft slab by integrating the Computer Aided Design (CAD) software and simulation. Generally the main purpose for using computer simulation software is to support decision making which improved efficiency and reduce cost (Klingstam and Gullander 1999). Special purpose simulation software "Simphony" is used to model the pouring time and examine the different scenarios to determine the sensitive parameters (Hajjar and AbouRizk 1999). The required amount of concrete is calculated automatically through "AutoCAD" software. Furthermore, Simphony software is applied to define the relevant sensitive parameters that need to be taken into consideration for this operation. Defining sensitive parameters help the project staff to focus on the important parameters that influence the concrete pouring time.

The model proposed in this paper connects Simphony with AutoCAD software by using Visual Basics for Applications (VBA) and Microsoft Access software, both of VBA and Microsoft Access are transparent to the users. VBA exports the object (2D or 3D) properties to Microsoft Access which is accessed by Simphony .This arrangement requires no special interface as the connection establishes by issuing the command of running the VBA on AutoCAD command line and choose the right module from a pop up box.

2 BACKGROUND

The Connection between CAD and simulation software has been investigated in industrial and construction fields. AutoCAD is often used to document proposed factory arrangement, including the placement of tools, material handling systems, and physical arrangement, as well as testing for clearances (McGinnis et al 2006). The cost effective way to integrate CAD and simulation is involved

sharing information between two distinct systems by extending each (AbouRizk and Mather 2000). For example, Moorthey (1999) establish the connection in industrial field by generating a formatted ASCII flat file (SDX file) describing the manufacturing data and translate the SDX file into a simple simulation model ; Xu and AbuRizk (1999) introduce the integration of CAD system with computer simulation for construction projects which is achieved by exporting the product physical attributes, their relationship and the methods from CAD to a product hierarchy (PH) which has been accessed by the simulation. AbouRizk and Mather (2000) also used an add-in program to AutoCAD software for relating and extracting the object information from AutoCAD, after that translate it to simulation information format. As we can see, the main concept is the same which exports the AutoCAD object attributes to a format can be accessed by simulation software.

The proposed model components are presented in section 3. Definitions of sensitive parameters are provided in section 4. Section 5 applies the model to a real operation, followed by the conclusion of the paper.

3   MODEL COMPONENTS

The proposed model is developed using three different software packages that work together to send information from AutoCAD to Simphony. Figure 1 illustrate the activity chart of the model
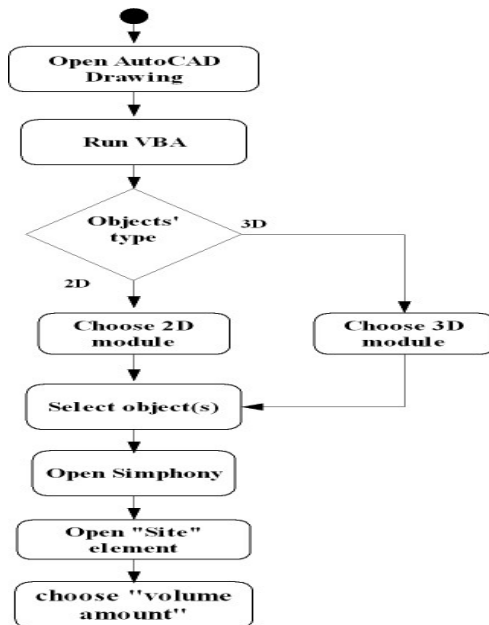

Figure 1: Software's activity chart

The model components are:

3.1   AutoCAD 2005

AutoCAD 2005 software is used to provide the drawing of the raft slab. Two "VBA" files are developed "cad_simph.dvd" and "cad_simph_3D.dvd" for sending the volume amount of objects to Microsoft Access file. (first file for 2D and second file for 3D objects).

3.2   Microsoft Access 2000

A Microsoft Access file called "cad_simph.mdb" is developed to receive AutoCAD's data and make it available for Simphony' modeling element.

3.3   Simphony.Net

Simphony is a special purpose simulation (SPS) tool. It is developed with the objective of providing a standard, consistent and intelligent environment for both the development as well as the utilization of construction SPS tools (Hajjar and AbouRizk 1999). A simulation template called "pouringconcrete" is generated to create simulation model that demonstrate the pouring concrete operation (as shown in Figure 2 and Figure 3). "pouring_concrete" is a discrete-event template in which the state of a model changes at only a discrete, but possibly random, set of simulated time points (Schriber and Burnner 1999).

Figure 2 and Figure 3 show the Simphony's main and child elements with their parameters and output statistics. The description of the element as follows:

3.3.1   Trucks

This element represents a group of trucks mixer fleet, each group is assigned to a certain batch plant and trucks returns to same batch plant after feeding the concrete pump, it can connect only to "batchPlant" element. The trucks elements' parameters are:

- Capacity: Truck's capacity in cubic meters.
- Espeed: Truck's speed in case of empty truck in km/hr
- Lspeed: Truck's speed in case of loaded truck in km/hr
- NoOfTruck: Number of trucks in the fleet that are assigned to one batch plant
- Type: Truck's type.

Cycle Time is the only statistic for this element and represents the cycle time of the truck.
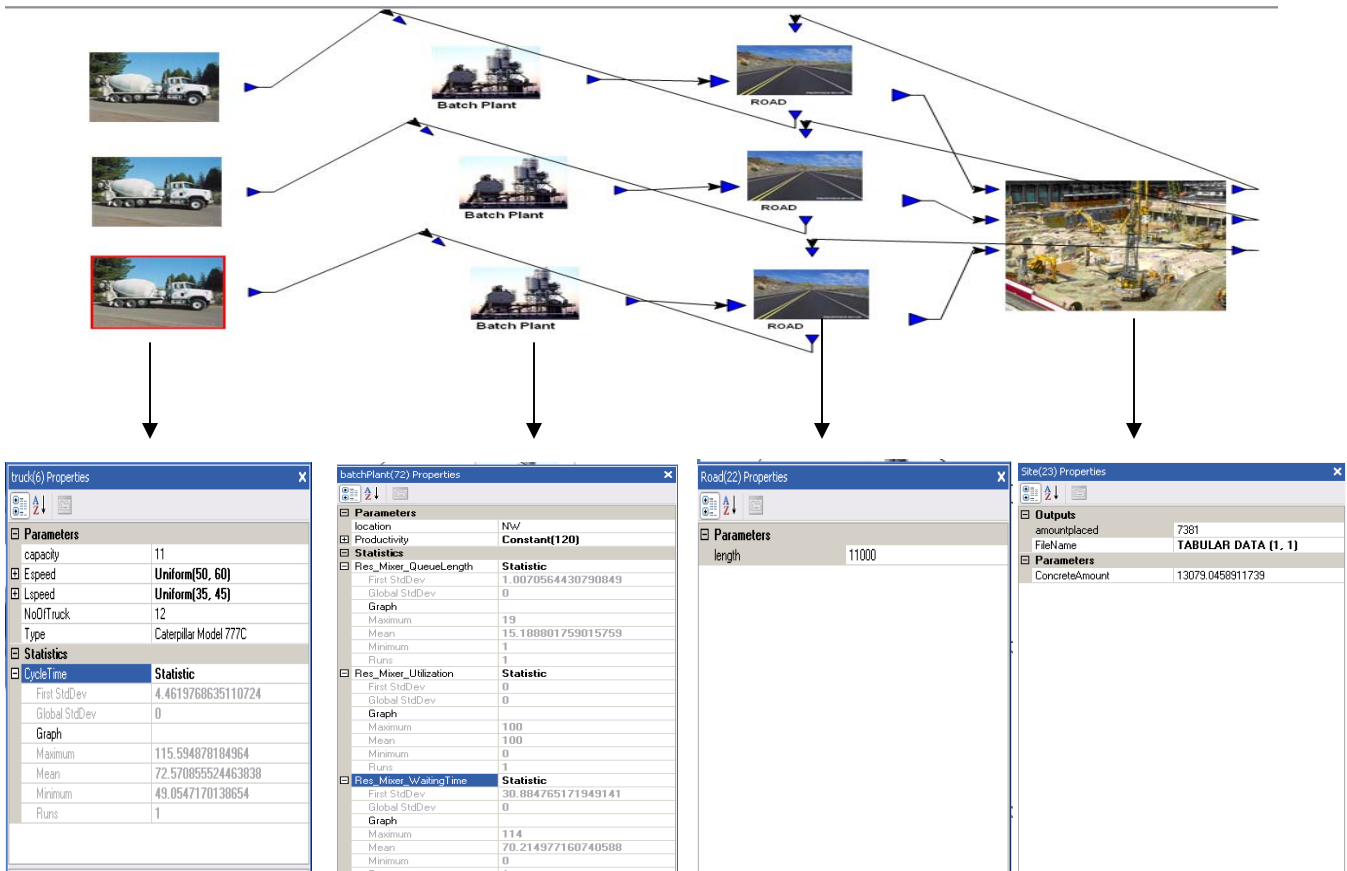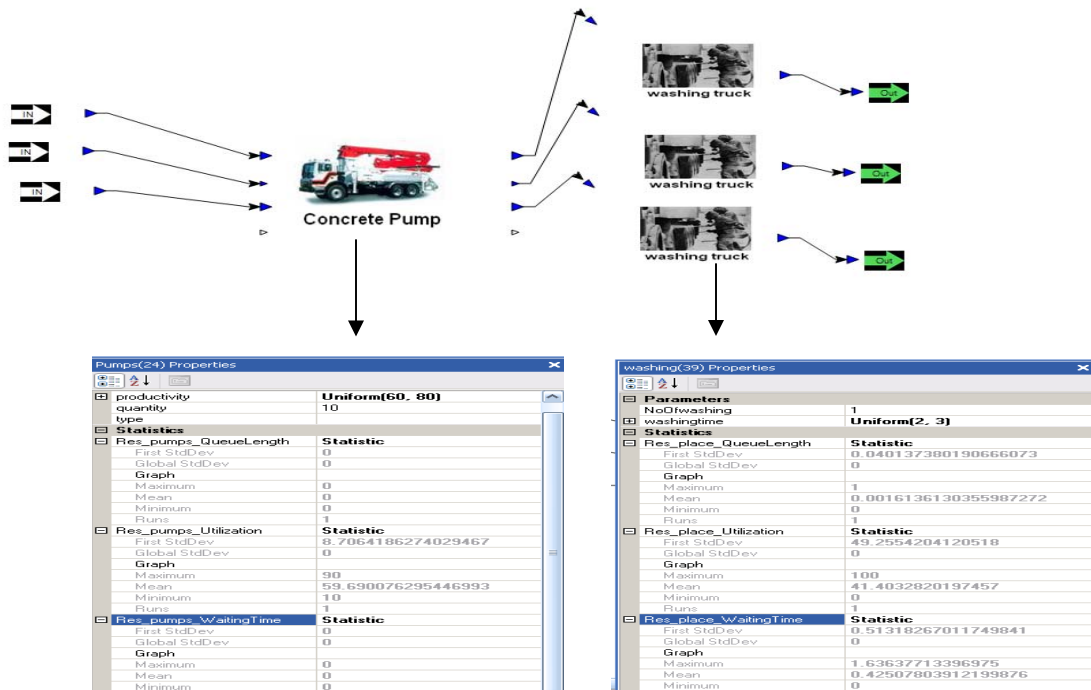
Figure 2: Simphony's elements – main window

Figure 3: Simphony's elements – Child window

3.3.2 BatchPlant

This element represents one batch plant and can connect only to the "road" element. There are two parameters for this element; first is "location" which shows the location of batch plant and the second one is "Productivity" that shows the batch plant's productivity. The output statistics of this element are:

- Res_Mixer_queueLength: This statistic shows numbers of trucks which have to wait for batch plant's mixer resources, lower number means higher efficiency.
- Res_Mixer_Utilization: This statistic provides the percentage of resource utilization, for ideal utilization the mean number has to be around ninety percent.
- Res_Mixer_WaitingTime: The time which truck has to be waited for mixer resource is shown by this statistic, lower number means a better arrangement. The "zero" in minimum is due to the first truck does not has to wait.

3.3.3 Site

This element represents the project's site where the required amounts of concrete will be poured. "Site" element has a child window which contains "InP", "pumps" , "washing" and "OutP" elements. The "Site" can be connected only to "batchPlant" element.

The only parameter for "Site" element is the "ConcreteAmount" which represents the required amount of concrete in cubic meters, the data input for this parameter is imported from "AutoCAD" drawing file as shown in figure 4. After the simulation is over, "amountplaced" field shows the amount of concrete which have been placed.
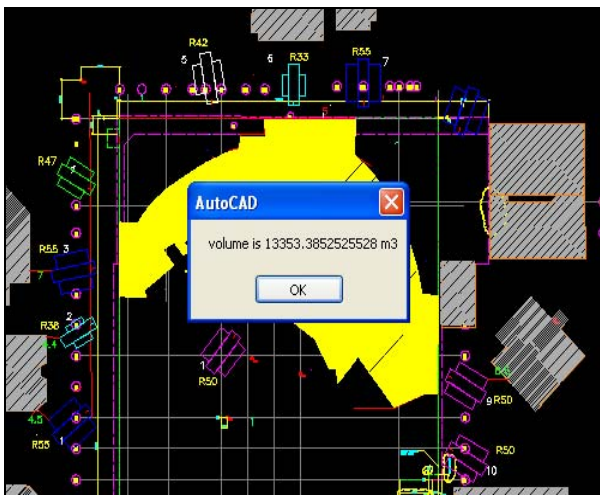

Figure 4: AutoCAD Output – The volume of the raft slab

3.3.4 Road

The road's length between batch plant and project's site (in km) is represented by this element. "Road" element can be connected only to "Site element". Length is the only parameter and there is no output for this element

3.3.5 InP

This element represents the input port for child window. Every "input" element produces an input port in the parent element (Site). There is no parameter or output for this element

3.3.6 Pumps

This element represents the concrete pumps and can be connected only to "washing" or "OutP" elements. Two minutes for initial preparation and one minute to finalize preparation are added to the duration of pumping. The element parameters are:

- Productivity: Amount of the concrete pumping rate in "m³/hr"
- Quantity: Number of pumps
- Type: type of pump.

The output's statistics have the same format and properties of batch plant's statistics.

3.3.7 Washing Element

This element represents the place for washing the concrete truck. The parameters of this element are:

- NoOfWashing: it represents the number of washing places
- WashingTime: it is the washing time.

The output's statistics have the same format and properties of batch plant's statistics

3.3.8 OutP

This element represents the output port for child window. Every "Output" element produces an output port in the Parent element (Site). There is no parameter or output for this element

4 SENSITIVE PARAMETERS OF THE MODEL

The goal of the model is to find out the time required to pour the amount of concrete. There are various uncertainties related to those operations. Following are few questions to consider:

1. What are the influencing factors on the time of pouring?

2. Do all factors influence the time in an equal manner?

This section answers these two questions by determining and analyzing the model's parameters. In the beginning, sensitive parameter is known as those parameters whose changes have a significant influence on the output. Additionally, the concrete pouring is usually performed by a sub-trade company, so determining the sensitive parameters of the operation helps the main contractor to identify the evaluation criteria of sub-contractors.

4.1 Changeable Elements Parameters

To ascertain the sensitive parameters, only one parameter is changed at a time while the others remain unchanged. The Following assumptions have been adopted during the execution of the model:
- The volume of the raft slab was 13353 m³.
- The numbers of trucks were distributed equally among the batch plant.
- Truck's capacity was 12 m³.
- The speed of empty truck was in the uniform distribution of 30-40 km/hr and speed for loaded truck was 50-60 km/hr.
- Truck's preparation time from arriving to pump and starting pumping was two minutes.
- Truck's release time from finishing pumping and leaving was two minutes
- Four batch plants with the same production rate were used in the model.
- The washing of the truck was in the uniform distribution of 2-3 minutes

The data analysis in following section shows that the most sensitive parameter is the distance between the site and batch plant trailed by following parameter (in order of sensitivity): the production of concrete pump, the number of concrete pump, the number of trucks and the production of batch plant.

4.1.1 Analyzing the Number of Trucks Parameter

The initial number of the trucks was generated as twenty trucks and was increased by four trucks at a time until the required time of pouring became constant. Adjustable model parameters were:
- The batch plant capacity was in the uniform distribution of 90-110 m³/hr.
- Concrete pump rate was in the uniform distribution of 65-75 m³/hr.
- Ten concrete pumps were used for pouring.
- The road's length from the site to each batch plant was 10 Km.

The simulation output in Figure 5 shows the relationship between the "number of trucks" and time of pouring the concrete.
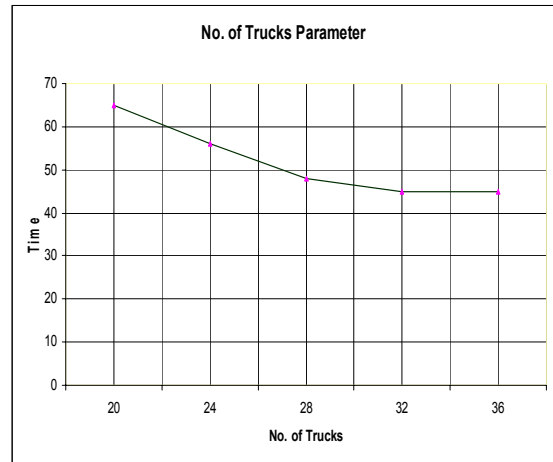

Figure 5: Simulation Output - Pouring time for various numbers of trucks.

Additionally, it shows that the optimal number of trucks for this model is approximately thirty-two trucks.

4.1.2 Analyzing the Production Rate For Batch Plant Parameter

The initial production rate of each batch plant was established as the uniform distribution of 50 – 70 m³/hr and was increased by 20 m³/hr until the required time of pouring became constant. Adjustable model parameters were:
- The number of trucks was thirty-two.
- The concrete pump rate was in the uniform distribution of 65-75 m³/hr.
- Ten concrete pumps were used for pouring.
- The road's length from the site to each batch plant was 10 Km.

The simulation result chart in Figure 6 illustrates the relationship between the "batch plant production rate" and time of pouring the concrete. Furthermore, it shows that the optimal uniform distribution of the batch plant production rate for this model is around 130-150 m³/hr.
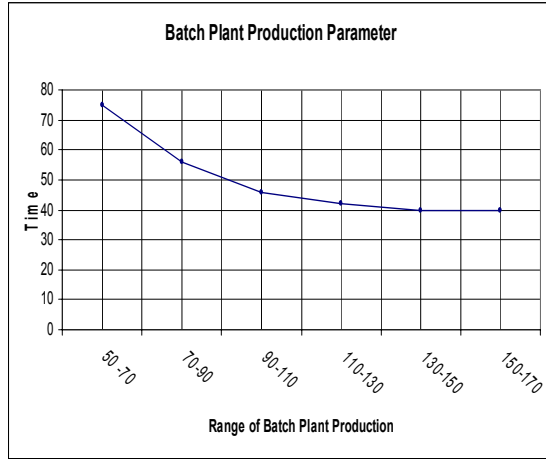
Batch Plant Production Parameter

Figure 6: Simulation Output - Pouring time for various Batch plant productions parameter

4.1.3   Analyzing the Length of Road Parameter

The initial length of the road parameter was generated as 5 KM and increased by 10 km at a time up to 45 Km. The changeable model parameters were:
- The number of trucks was thirty-two.
- The batch plant production rate was in the uniform distribution of 130-150 m³/hr.
- Ten concrete pumps were used for pouring.
- The concrete pump rate was in the uniform distribution of 65-75 m³/hr.

Figure 7 shows the result of the simulation with various lengths of the road parameters. Moreover, the chart line shows a strong relationship between road's length parameter and time of concrete pouring.
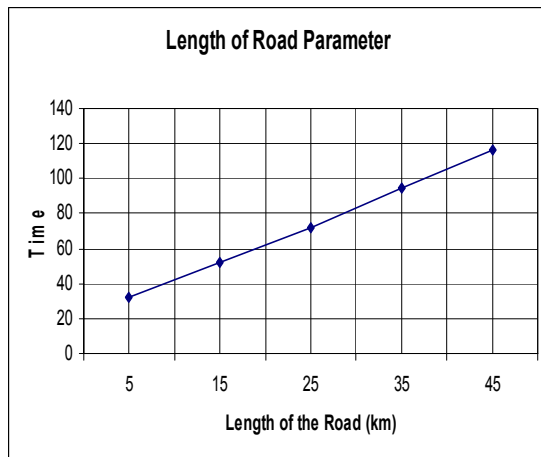
Length of Road Parameter

Figure 7: Simulation Output - Pouring time for various lengths of road parameter

4.1.4   Analyze the Production Rate of Concrete Pump Parameter

The initial production rate of concrete pump was initialized as the uniform distribution of 30– 40 m³/hr. and increased by 15 m³/hr until the required time of pouring became constant or reached the maximum pumping rate (100 m³/hr). The adjustable model parameters were:
- The number of trucks was thirty-two.
- The batch plant production rate was in the uniform distribution of 130-150 m³/hr.
- Ten concrete pumps were used for pouring.
- The length of the road from the site to each batch plant was 10 Km.

The simulation result chart in Figure 8 demonstrates the relationship between the "concrete pump production rate" and the time of pouring the concrete. Additionally, it shows that the optimal uniform distribution of concrete pump production rate for this model is approximately in the uniform distribution of 75-90 m³/hr.
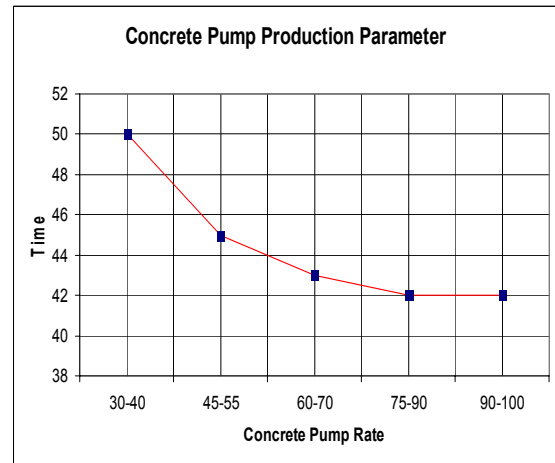
Concrete Pump Production Parameter

Figure 8: Simulation Output **-** Pouring time for various concrete pumps' productions rate parameter.

4.1.5   Analyzing the Number of Concrete Pump Parameter

The initial number of concrete pump was established as three and increased by one pump until the required time of pouring became constant. The adjustable model parameters were:
- The number of trucks was thirty-two.
- The batch plant production rate was in the uniform distribution of 130-150 m³/hr.
- The concrete pump rate was in the uniform distribution of 75-90 m³/hr
- The length of the road from the site to each batch plant was 10 Km.

The simulation result chart (Figure 9) presents the relationship between the "number of concrete pump" parameter and the time of pouring the concrete. Moreover, it shows that the optimal number of concrete pump for this model is five pumps.
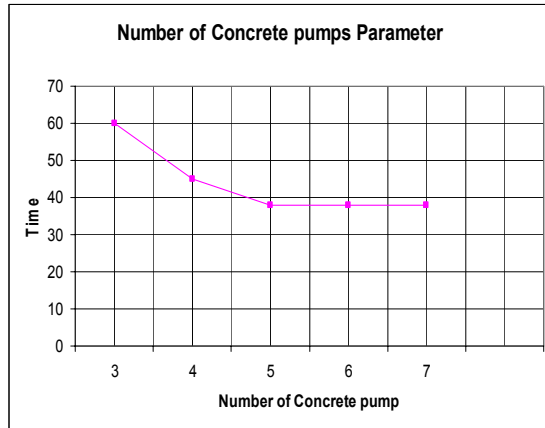

Figure 9: Simulation Output - Pouring time for various numbers of concrete pump parameter

4.2   Analysis of Sensitivity of Parameters

The five line charts (Figures 5, through 9) of relationships between parameters and pouring time provide the following information:

- The curve's slop for number of trucks (Figure 5) is high in the beginning until it reaches a threshold number (twenty eight for this model). After this number the curve's slop decreases sharply which means this parameter is highly sensitive up to a certain number of trucks and then sensitivity is decreased strongly after this number.
- The first part of the batch plant's production curve (Figure 6) which is up to 70 m³/hr may be neglected because 70 m³/hr is the minimum practical production rate of the batch plant. The slope of rest of the curve is not that high which means that it is a moderate sensitivity parameter.
- Because of the high value and stability of the road's slope (Figure 7): this parameter is considered as highly sensitive parameter.
- The concrete pump's production rate under "50 m³/hr" may be neglected as well (Figure 8) because 50 m³/hr is the minimum practical production rate for concrete pump. On the other hand, the slope of rest of the curve is higher than batch plant's curve (Figure 6) and Number of Concrete pump (Figure 9).
- There is a high similarity in behavior of the trucks' parameter curve (Figure 5) and the

number of concrete pump parameter curve (Figure 9). Both of them have a threshold number. On the other hand, the slope in number of concrete pumps' curve (Figure 9) is higher than the truck's curve (Figure 5) in the area before the threshold numbers.

5   APPLYING THE MODEL

As a part of planning for pouring the concrete for a upper raft slab - which is the largest in Canada and the third in world - for "The Bow " project in downtown Calgary, the proposed model is used to predict the required time for this operation. The available information for pouring concrete operation during the planning phase was as follow:

- The theoretical concrete amount of the upper raft is 13753 m³.
- Four batch plants will be used to provide concrete. Table 1 shows the average distant from each batch plant to project site in km and the uniform distribution of the productivity rate for each batch plant in m³/hr.

Table 1: Shows the distance between the site and each Batch plant and their productivity rate.

	Batch plant No. 1	Batch plant No. 2	Batch plant No. 3	Batch plant No. 4
Distance Km	18	21	4	20
Productivity m3/h	150 - 160	125-135	115-125	85-95

- Twelve concrete pumps will be used; four of them feed another four pumps which mean the effective pumps are eight. The uniform distribution of pump's productivity is 55-65 m³/hr
- Sixty fives trucks will be used , third with a capacity of 7 m³ , third with capacity of 9 m³ and third with capacity of 12 m³

When these scenarios are simulated (as shown in Figure 10 and 11) the required time according to simulation was thirty five hours and half.
The pouring concrete operation was held on May 9, 2008 from 9:00 pm to Sunday May 11 at 11:30 am which was thirty eight hours and half. The actual poured amount of concrete was 13777.5 m³. The difference between the model predictable time and actual was around 8.5 %. This time difference was likely due to:

- The model considered all pumps will start together; in fact, first pump started at 9:00 pm and last one started at midnight.
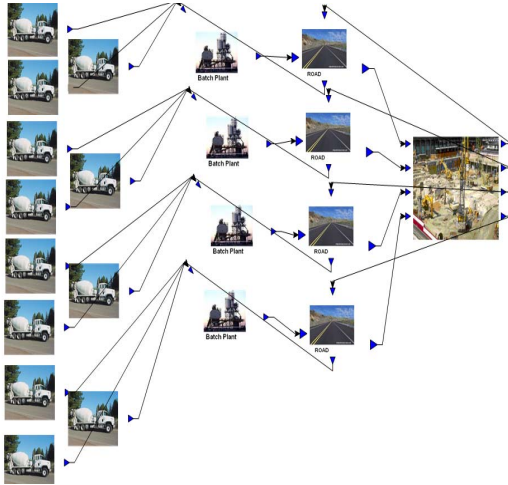- Two pumps are replaced during the pouring which took around 1 hour.

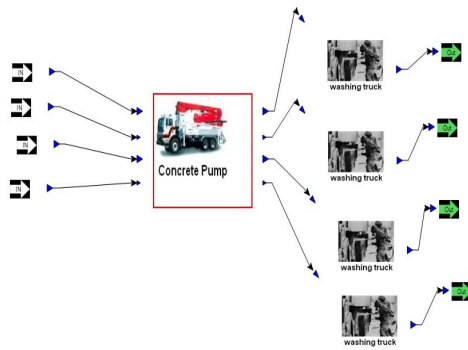Figure 10: The upper raft model for "The Bow" Project

Figure 11: The lower raft model for "The Bow" Project – Child Elements

6 CONCLUSION

The operation of pouring the concrete of raft slab in a downtown project needs a special arrangement to finish it in the required time. The proposed model offered an easy way to transfer data of "Raft Slab" from AutoCAD to Simphony simulation software. The model helps the construction staff for defining the ideal parameter for different elements in order to finish the pouring operation in right time. Moreover, the proposed model helps the main contractor to choice the right sub-contractor for concrete pouring operation by determining the level of sensitivity for changeable parameters. The model was applied to a practical case for pouring the upper raft slab for "the Bow" project; the result was in range of a 10% error. The model can improved by taking into consideration the situation of more than one projects shares the same batch plants and also the slow down in the start of the pouring the concrete

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