

AP2-EARTH: A SIMULATION BASED SYSTEM FOR THE ESTIMATING AND PLANNING OF EARTH MOVING OPERATIONS

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ABSTRACT

Simulation studies are well suited for the analysis of earth moving operations for many reasons. First, projects generally involve some form of resource interactions where certain equipment must obtain certain resources before proceeding. Second, task durations are highly empirical and are thus suited for stochastic modeling. And third, projects are affected by external processes such as breakdowns and external traffic. Simulation can take all of those elements into account and help estimators gain greater insight into the interactions and productions of earth moving projects.

This paper overviews and discusses the features AP2-Earth, a computer tool for the simulation, analysis and estimation of large earth moving projects. Data for the model can be imported from an equipment management module and exported to a reporting or estimating module. AP2-Earth allows users to experiment with a number of variables such as the equipment combinations or the road layouts and examine the effect on production.

1 INTRODUCTION

Simulation has been used extensively in many areas of Construction Engineering starting with the introduction of CYCLONE by Halpin (1977). This methodology has been the basis for a number of construction simulation systems. Most of these systems are general in nature forcing users to build models using abstract elements such as activities, queues and resources. This allows for the modeling of scenarios of unlimited complexity and in any field. Further, if the basic building elements are not sufficient to a model a given situation, most systems also allow for the integration of programming code in the form of user inserts or add-ons. Although these systems prove extremely flexible and powerful from an academic standpoint, those who can benefit from its power the

most, the industry practitioners, have not embraced it. The generality and complexity of general purpose simulation systems meant that industry members were forced to learn the equivalent of a new language or hire an expensive simulation consultant to perform the required analysis. In the construction industry, simulation can be most beneficial during the estimating stage where limited time is available and costs incurred are typically not easily recovered since only a small amount of estimates lead to a successful contract award. Construction practitioners require a simulation tool that is easy to use and tailored to their specific requirements with results that can be directly used as part of other decision support systems such as computer estimating programs.

Special purpose simulation (SPS) was proposed by AbouRizk and Hajjar (1997) to address the stated issues. The idea is to develop user friendly simulation tools native to the application domain itself. This typically involves the development of custom user interfaces, simulation engines, support libraries and integration modules. By specializing, the full-fledged flexibility of a general purpose simulation tool is lost. However, the resultant benefits far outweigh the limitations. SPS tools allow industry practitioners to use simulation systems without prior knowledge of simulation theory. Further, by eliminating generic modeling elements and presenting the user with a familiar domain specific environment, simulation models can be built with great ease, speed and accuracy.

This paper overviews a SPS system for the analysis of earth moving operations called AP2-Earth. The tool was developed with the objective of providing earth moving contractors in the Province of Alberta, Canada with a system that can automate the traditionally time consuming and manual process of preparing earth moving estimates for large and complex projects. The emphasis of this paper is on the features and capabilities

of the developed system. Interested readers are referred to Hajjar and AbouRizk (1997) for more detailed discussion on the internal design and development aspects.

2 EARTH MOVING FUNDAMENTALS

In order to understand the true benefits of an automated earth moving simulation system such as AP2-Earth, it's important to present some background information about the processes involved and the traditional method of preparing project estimates.

Earth moving is a specialized construction field where large quantities of earth are moved from one location, generally referred to as the cut or the source, to an another location referred as the fill or the placement. Examples of such projects include overburden removal for mining operations and construction of earth filled dams. Earth moving projects consist of many interacting processes including preparation, loading, hauling, dumping and spreading. Preparation is used if the earth is not suitable for immediate loading and requires ripping. Loading is the process of transporting earth from the prepared earth pile into incoming trucks. This is done using loaders, shovels or backhoes. Hauling involves trucks traveling through roads with varying slopes and ground conditions as well as traffic intersections in order to transport earth and return. Dumping is the transfer of earth from the trucks into a spreading pile. This pile is spread by a number of dozers as part of the spreading process.

The travel velocity of trucks is dependent on the total resistance of a given road segment. Total resistance is composed of grade resistance and rolling resistance. Grade resistance is a measure of the force that must be overcome to move trucks over uphill slopes. Rolling resistance is a measure of the force that must be overcome to roll or pull a wheel off the ground.

2.1 Determination of Number of Production Units

The most important element of preparing a cost estimate is the determination of the number of production units to use. Once this is obtained, other supporting equipment and labour are added to obtain the overall cost. To obtain the number and type of production units, construction estimators rely on the client's specifications to arrive at certain required data. This includes the following information:

1. The overall site layout including the location of the source and placement areas.
2. Overall quantities to be prepared, hauled and placed.
3. Properties of the haul paths including distances, grades and rolling resistance.

The first step is to decide on the type of excavator to be used. This depends on equipment availability, type and quantity of the soil to be moved, and the schedule requirements of the project. After deciding on a given excavator, the type of trucks to be used is determined. This again depends on equipment availability, type of excavator and haul path properties. Next, the cycle time of the trucks is determined. The elements of a complete truck cycle are:

1. Loading time
2. Travel loaded time
3. Dump time
4. Travel empty time

Loading time is calculated using the excavator's expected production rate plus any allowance for waiting and positioning. The travel loaded and travel empty durations are obtained by first dividing the haul paths into many segments; each with a relatively uniform grade and rolling resistance. This information along with equipment manufacturer specifications is used to determine the expected travel speed of the trucks across each road segments. Travel speed along with the length of each segment is used to arrive at the travel durations. Dump time is determined using historical information.

The truck cycle time along with the truck capacity is used to calculate the number of trucks required to match the production capability of the excavator. Further, extra trucks are generally made available on site in case of breakdown and as a replacement for trucks undergoing maintenance. The described estimating procedure is adequate for simple cases where single source and placement areas are present and a single type of truck is used. This process becomes time consuming and tedious in the case of multiple source and placement locations, complicated haul paths with many changes in total resistance, and varying types of trucks. Further, estimators cannot accurately determine the waiting duration associated with the excavator usage or as a result of fleet interactions between multiple paths.

3 SIMULATION OF EARTH MOVING PROJECTS

AP2-Earth was developed to address the stated concerns and simplify the tender preparation process on large and complex earth moving projects. To ensure the tool's acceptance, it was built with the capability to integrate with other modules including equipment inventory databases and estimating programs. These supporting modules were also developed and provided with the main simulation module. A graphical depiction of the overall AP2-Earth modules and how they relate is illustrated in Figure 1.

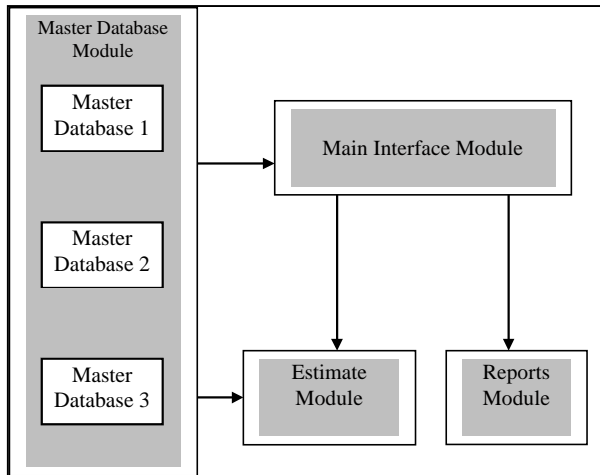


Figure 1: AP2-Earth Modules

The master database module consists of standard equipment and labour specifications that are available for use by the contractor. The database stores various equipment properties, some of which can be used directly in the simulation environment or at a later stage for estimation purposes. The main interface module is where simulation modules are built. Equipment data can be imported from the master database modules. Two other modules are used to examine the simulation results. The first is the reports module which provides various types of information ranging from high level production reports to detailed equipment performance and utilization reports. The other is the estimate module which allows users to develop estimates and link certain inputs directly to the simulation results. The following sections will provide a more detailed overview of each module.

3.1 Master Database Module

The master database module is used to construct standard equipment and labour databases. The objective is to reduce the amount of data entry that must be done in order to produce a complete simulation model by defining commonly used equipment only once. This information can then be imported into the AP2-Earth simulation environment where it can be further customized. The main user interface for this module is shown in Figure 2. A sample of the elements that can be defined in this module and some of their attributes are given in Table 1. The usage column in Table 1 indicates whether a given attribute is used as part of the simulation or later to prepare an estimate.

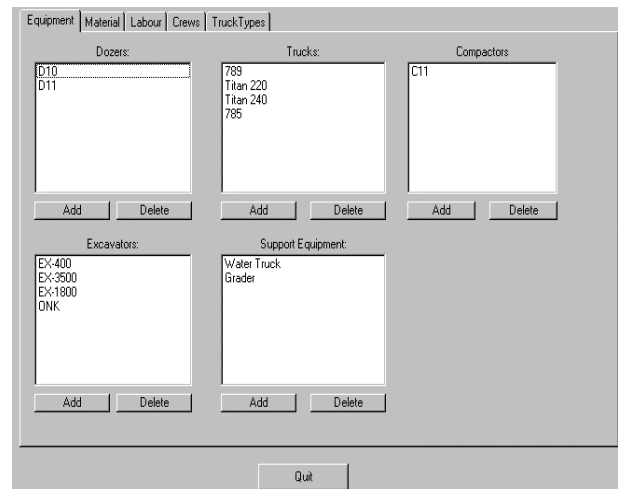


Figure 2: Main Screen of the Master Database Module

Table 1: Sample Master Database Elements

| Object | Property | Data type | Usage |
|------------|---------------------|--------------|----------------------|
| Truck | Truck type | Reference | Simulation |
| | Operating Cost | Currency | Estimate |
| | Quantity | Integer | Simulation, Estimate |
| | Capacity | Integer | Simulation, Estimate |
| | Dumping Time | Distribution | Simulation |
| Labor | Rate | Currency | Estimate |
| Crew | Elements | Collection | Estimate |
| Truck Type | Travel Curve Loaded | Function | Simulation |
| | Travel Curve Empty | Function | Simulation |

Note that some attributes are of the distribution data type. This means that a stochastic distribution can be used to model the given parameter during simulation. Users define the type and parameters of a given distribution using the dialog box shown in Figure 3.

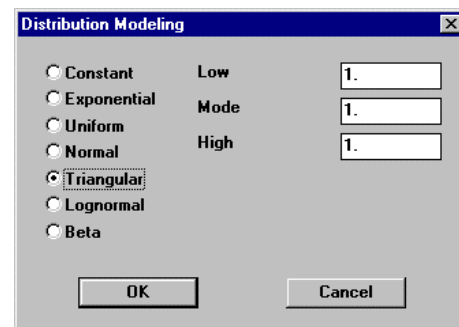


Figure 3: Distribution Definition Dialog Box

One way to get the input required for calculating travel durations across a given road segment would be to have the user enter the velocity of the trucks across each road segment. However, this would require a great deal of time and effort on the part of the user to get the information. Instead, it was decided to allow users to define a travel curve for each type of truck. These curves give the expected travel speed given the total resistance. Information to construct such relationships can be done using readily available equipment performance handbooks. The user interface for building these curves is shown in Figure 4. Users simply provide a minimum of seven data pairs of total resistance versus velocity for the empty and the loaded cases. Once this information is entered a mathematical curve is fitted and the results are shown graphically as illustrated Figure 4. The objective of fitting a mathematical curve to the data is to reduce the amount of calculation that must be done during the simulation. Once a given set of curves is defined for a specific truck type, it can be assigned to any truck in the database.

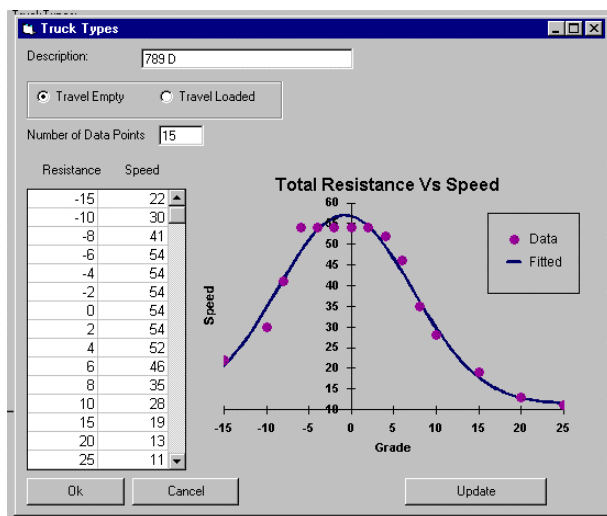


Figure 4: Travel Speed Curve Definition

3.2 Main Interface Module

The main interface module is where the simulation models can be built. Standard earth moving elements are used to build general earth moving scenarios. The user can create and manipulate several objects such as sources, placements, road segments, intersections and trucks. Figure 5 displays the main windows along with descriptions of the main elements. All objects can be created by clicking on the appropriate icons or by selecting them from the component menu.

Each object holds several properties that define its behavior during the simulation. By double clicking on an

object, the corresponding property window is displayed with the current attribute values. A sample property window for the intersection dialog box is shown in Figure 6.

3.2.1 AP2-Earth Objects

The following modeling elements are available for the definition of earth moving scenarios:

1. Source: A source object contains all necessary information for the preparation and loading processes at one cut. Each source contains dozers that are used for preparation and excavators for loading incoming trucks.
2. Placement: A placement object contains all necessary information for the spreading, dumping and compacting processes. Each placement contains dozers and compactors used in their respective process. Other properties of placements include the maximum number of trucks allowed in the dump area at any time.
3. Dozer: Dozers are used to represent any kind of preparation or spreading equipment. They are defined within a source or a placement object.
4. Excavator: Excavators are used to represent any kind of loading equipment. They are created and manipulated within each source object. Excavator properties include the loading time with all trucks defined in the simulation.
5. Road Segment: Road Segment objects are used to model a single-lane, one-way road segments and to construct a travel path for the trucks. Graphically, road objects can be extended and rotated to enable easy visualization of the project. Hauling roads that contain multiple lanes can be modeled by using two or more road segments side by side. Properties of road segment objects include grade, rolling resistance and distance. Users can also specify whether passing is allowed. If passing is not allowed, the queuing effect due to trucks with varying velocities is modeled.
6. Intersections: Intersections allow the modeling of interactions between truck fleets and between trucks and user defined external traffic processes. These objects usually add a delay to the hauling duration making the model more realistic. AP2-Earth Intersections behave like 4-way stop intersections. Entities arrive and wait at each lane. When the blocks needed for traversing the intersection are free the entities proceed and block all the other traffic that require some or all of the reserved blocks. After traversing the intersection, the entity frees up the reserved blocks and the next entity proceeds if possible.

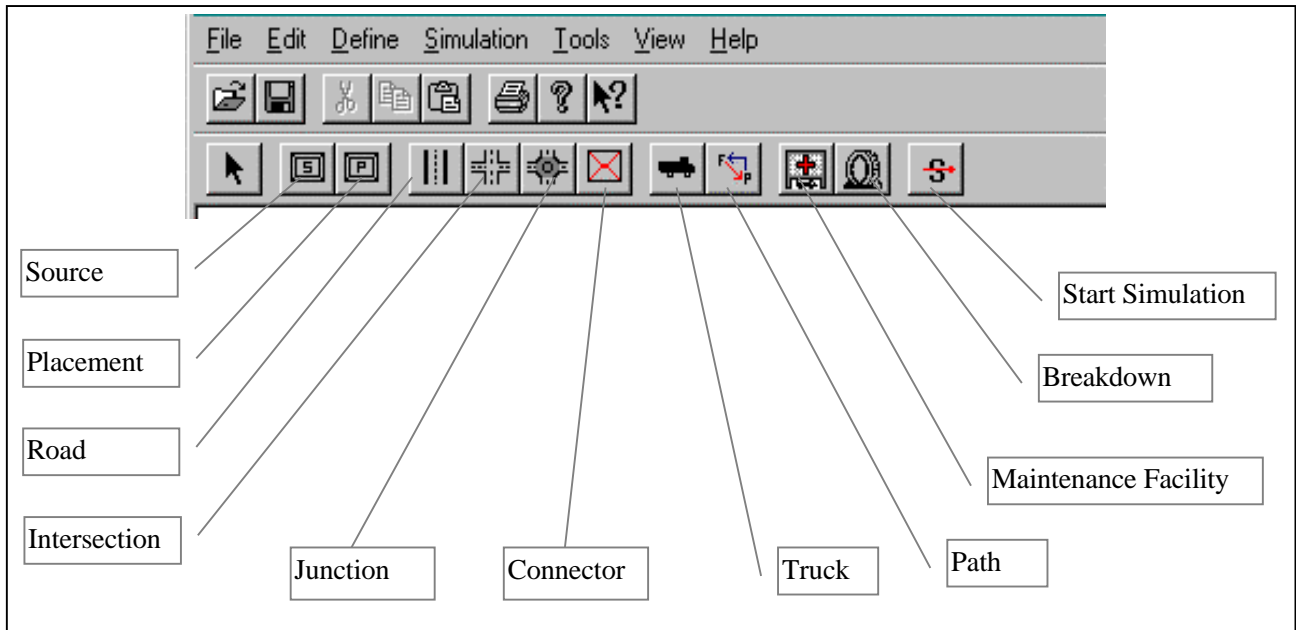


Figure 5: Main Interface Module

7. Truck: Trucks are the main entities of the hauling simulation process. Their properties include capacity, loading time, and the paths to be followed.
8. Path: A path is a list of connected road segments and intersections that define the travel paths of trucks. Users can assign one “travel loaded path” and one “travel empty path” to each truck.

- place sources and placements,
 - build road layout using roads, connectors, intersections and junctions,
2. Create paths
 - create one or more “Travel Loaded” path and assign hauling quantities,
 - create one or more “Travel Empty” path,
 3. Create Truck(s)
 4. Define Source(s) and associated properties.
 - create at least one excavator and define loading durations with truck(s),
 - define the amount of earth already prepared and amount to be prepared,
 - if preparation is required, create dozers,
 5. Define Placement(s) properties
 - define amount to spread,
 - if spreading required, create dozers,
 - define amount to compact,
 - if compacting required, define compactors.
 6. Specify Simulation Options

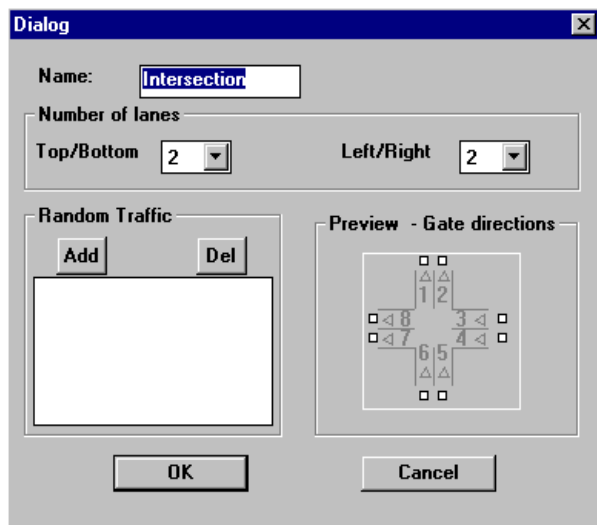


Figure 6: Intersection Object Dialog Box

3.2.2 Model Build Steps

Users build an AP2-Earth simulation model using the following general steps:

1. Construct project layout using the interface,

After completing the above steps, simulation can be started. This displays a progress monitor indicating the processes that are active and the current simulation time. After simulation is complete results can be accessed in the report or the estimate modules.

3.3 Reports Module

The reports module is used to present users with various types of reports that indicate the performance of the simulation. The information can be used to identify system bottlenecks such as a shortage of trucks or a

extended delay at a certain intersection. Advanced users requiring more detailed information can easily create their own reports because this module is implemented as a Microsoft Access database. The reports available are as follows:

1. The “General Simulation Report” provides the process level information such as total quantities and hourly productions.
2. Equipment reports for trucks, excavators and dozers provide detailed equipment level statistics including information on number of cycles, cycle duration, utilization and hourly production.
3. Production graphs show system production as a function of simulation time. These graphs indicate whether the model reached a steady or transient state.

3.4 Estimating Module

The estimating module was built to demonstrate AP2-Earth’s capability to integrate with many supporting systems. After the simulation is complete, the estimating module can first be used to create a starting template based on the information defined in the main interface module. This template contains all the equipment used

and broken down by the source and placement areas. The user interface for this module is shown in Figure 7. It consists of a spreadsheet like environment where cells can contain text, numbers or formulas. Data can be easily imported from the master database module. Information such as support equipment, labor and crews can be imported and automatically added to the spreadsheet.

The true integration capability of AP2-Earth is demonstrate through the estimate module’s capability to import information directly from the simulation. Specific cells on the spreadsheet can be linked to specific simulation outputs. The user first selects which cell to link and then presses the link button. This brings up the dialog box shown in Figure 8. The simulation information shown is arranged in a hierarchical manner to facilitate navigation. For example, referring to Figure 8, if the production of the preparation process at “Source A” is required, the user expands the tree branches in the following order: “Sources, Source A, Preparation Process”. When the tree branches are expanded, selecting “Average Production” causes the program to import the value from the simulation results and display the linking information at the bottom of the main screen.

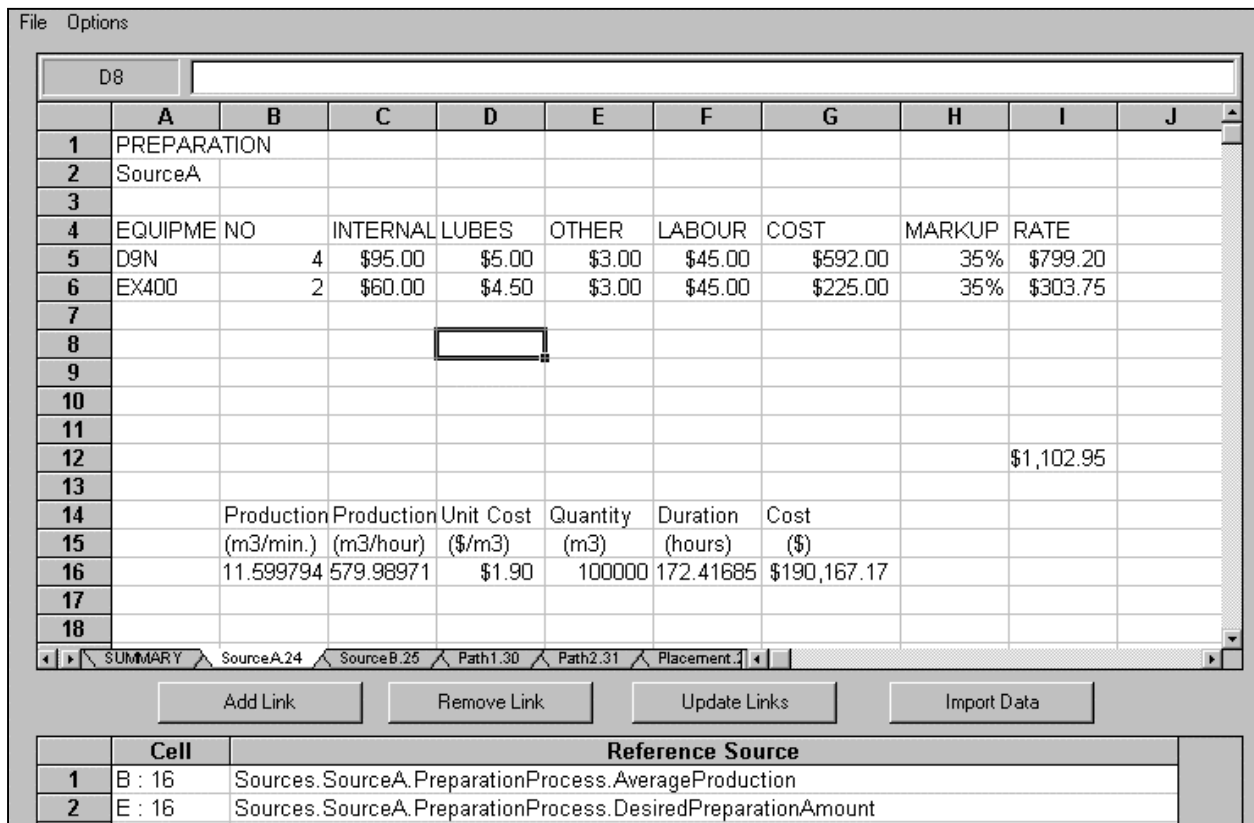


Figure 7: Estimate Module Interface

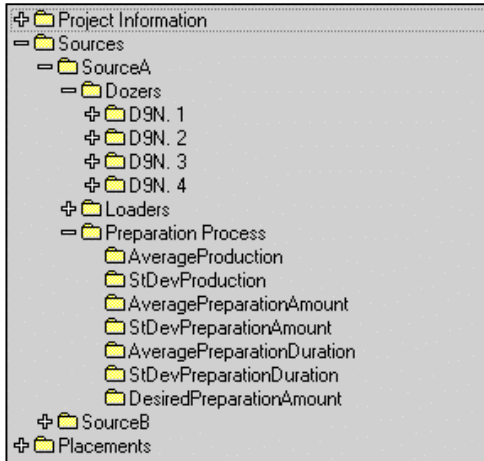


Figure 8: Linking Cells to Simulation Results

By providing a flexible linking structure and generating a standard template, the simulation results are made immediately available and used as part of the estimate. Further, users who become more familiar with the system, can use the integration capabilities to build more involved estimates. For example, the template currently utilizes the average production. However, by taking advantage of the other calculated parameters such as the standard deviation, users can build range estimates as opposed to point estimates. This allows for more accurate representation of the project and facilitates the calculation of risk and contingency.

3.5 Implementation Platform

The described modules were built using Microsoft Visual Basic and Visual C++. This allowed for the construction of highly visual interfaces that can run on the popular Microsoft Windows operating system. Interested readers can download the latest version of AP2-Earth using the Internet from the following home page address: <http://cem.civil.ualberta.ca>.

4 CASE STUDY

AP2-Earth was field-tested using data obtained from a case study on the Syncrude mine site in Alberta, Canada. The objective of this study was to verify the model's predicted parameters and examine whether the tool can be used in a real life setting.

An AP2-Earth simulation model was constructed as shown in Figure 9. The two source objects on the left side represent the pit locations. On the right, two placement areas are used to represent the dump locations. The shown intersections were used to model the possible interactions. The main results of the simulation are shown in Table 2. AP2-Earth was able to predict the actual production at the two source areas to an accuracy of 93.9% and 90.1%. The full case study results are presented with more detail in Hajjar and AbouRizk (1997).

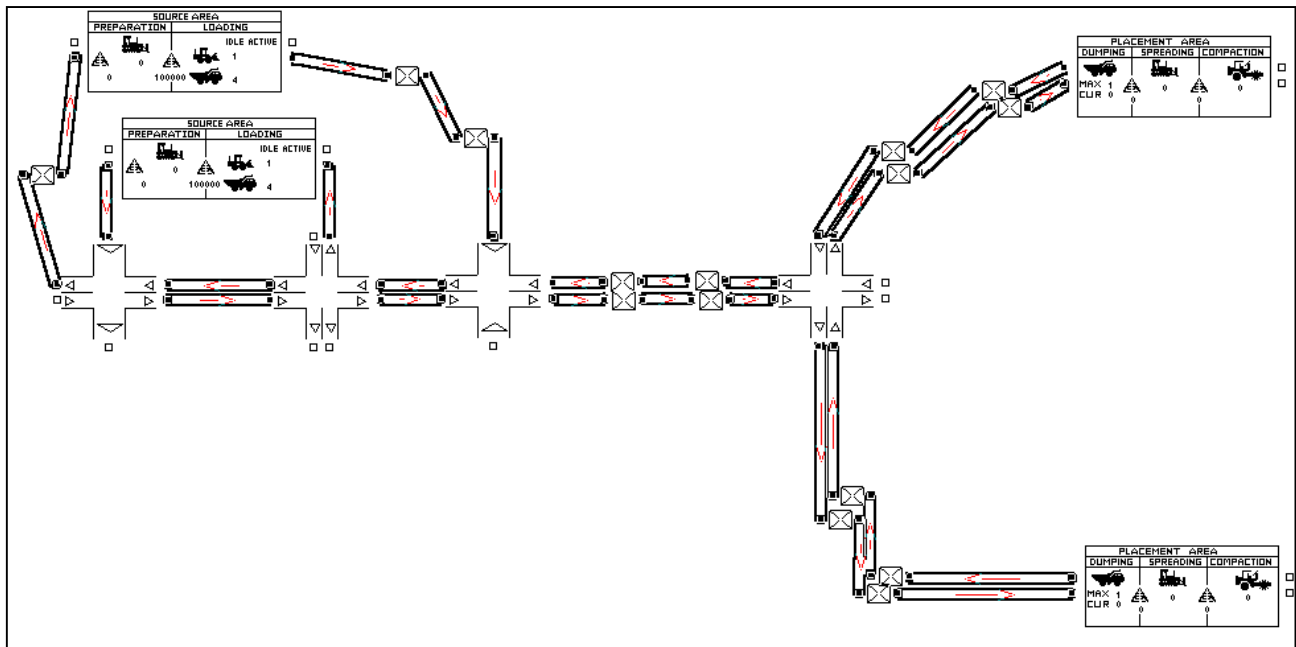


Figure 9: Case Study Model Representation

Table 2: Case Study Results

| Source Area | Observed Production (LCM/Hr) | Predicted Production (LCM/Hr) | Dev. | Error |
|-------------|------------------------------|-------------------------------|------|-------|
| A | 1190 | 1117 | -73 | -6.1% |
| B | 840 | 923 | 83 | 9.9% |

4 CONCLUSIONS

By designing and implementing a tool where simulation models can be built using constructs native to the application domain, the opportunity for industry practitioners to realize the benefits of simulation was created. AP2-Earth was built with this objective as models are constructed using earth moving elements. Reports are presented in a familiar manner and data can be easily imported from equipment databases and exported to other decision support systems.

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