University of Alberta

Modeling Reclamation Earthwork Operations Using Special Purpose
Simulation Tool

by

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ABSTRACT

Earthwork operations in general are complex and difficult to schedule and control. Forecasting and controlling equipment productivity, activities cost and time, work quality, and best fleet scenario are challenging and critical for project success. The earthwork operations for reclamation add challenges and complications to common earthworks schedule and aspects such as placement locations and hauling routes…etc. The reclamation earthworks require that the soil layers structure before disturbing the land must remain the same after placement, which means different equipment optimization due to soil profile specifications which require specific pieces of equipments, hauling routes arrangements depending on locations of dirt material from a specific required type, and stockpiling spots availability. Computer simulation is a proven methodology for planning and controlling different aspects of the construction industry and especially for earthwork operations. Numerous practical simulation tools have been developed to model earthwork operations, however, they either do not deal with reclamation earthworks as a unique and independent earthwork operation due to retaining the soil profile before disturbance in the same order after placement, or they deal with a single piece of equipment only, rather than the entire equipment fleet. This thesis presents a special simulation tool to model earthwork operations for reclamation using Simphony.NET. The outcome of this simulation tool is to incorporate the entire equipment fleet along with the flexibility to manipulate and control each piece of equipment, soil profile specifications, excavation and placement locations, and modeling different hauling routes. This thesis also

includes an actual case study to examine the applicability and model validation using general purpose template of Simphony.NET.

ACKNOWLEDGMENTS

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LIST OF ABBREVIATIONS

ACDs: Activity Cycle Diagrams

ANN: Artificial Neural Network

ARD: Acid Rock Drainage

DES: Discrete Event Simulation

DTM: Digital Terrain Modeling

Dvmax: Distance to reach the maximum speed

EPEA: Environmental Protection and Enhancement Act

ERCB: Energy Resources Conservation Board

ES: Equipment Selection

GA: Genetic Algorithm

GIS: Geographic Information System

GPS: General purpose simulation

GR: Grade Resistance

HLA: High Level Architecture

LFH: Litter, Fibric and Humic material

MMS: Mining Method Selection

NMW: North Mine Wall

PDF: Probability Distribution Function

RR: Rolling Resistance

SER: Society for Ecological Restoration

SPS: Special Purpose Simulation

SSD: Stopping Sight Distance

STP: Shovel Truck Productivity

TKPH: ton-km-per-hour

TR: Total Resistance

VIMs: Vital Information Management system

CHAPTER 1 INRODUCTION

1.1 INTRODUCTION

This chapter introduces an understanding of reclamation earthworks and construction simulation, and discusses the thesis objectives and organization. First, reclamation's regulations, definition, earthwork phase, and planning are explained. Second, construction simulation's definition and approaches, and Simphony.NET's description are given. Third, thesis objectives in general, simulation objectives, and reclamation earthworks simulation and planning objectives are discussed. Fourth, the thesis organization is detailed.

1.2 EARTHWORKS OF RECLAMATTION

1.2.1 Mine Use and Regulations in Alberta

In Alberta, about 500 km^2 of land has been disturbed by oil sands mining since the 1970s. According to the Energy Resources Conservation Board (ERCB) (2009), oil sands deposits cover one sixth of the total area of the province. If certain environmental recovery procedures and regulations are not performed, the mining work covering this huge area will definitely cause negative environmental impacts due to pollution and ground disturbance. To reduce such environmental consequences and avoid legal issues during mining, health and environmental safety procedures can be applied during mining and construction period and

specific closure procedures must be developed, regulated and executed to allow for rehabilitation and/or reclamation of the land after working period is over.

The Government of Alberta has adopted the policy and the terms of the Environmental Protection and Enhancement Act (EPEA), which strives "to support and promote the protection, enhancement and wise use of the environment," and emphasizes governmental contribution in developing methods, research, and technology to achieve these objectives, also encouraging citizens' contributions, as well as penalties against polluters (EPEA Section 2 2010). EPEA includes a full chapter for reclamation, called "Conservation and Reclamation," in order to establish a regulatory system to control the reclamation.

1.2.2 The Difference between Restoration and Reclamation

There is a significant difference between reclamation and restoration. According to the Society for Ecological Restoration (SER) (2004), restoration is "assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed," while reclamation is returning the land back to a good ecological state, but not necessarily to the exact pre-mining ecosystem state (Raab 2010). In other words, reclamation's purpose is to restore the disturbed land to the pre-mine state as much as possible, because full restoration is, as Bengson (1998) argues, impossible to attain for the disturbed land. Generally, the purpose of reclamation is to enhance public safety, benefit from post-mined disturbed land, stabilize the terrain, and beautify the site view (SER 2004).

1.2.3 Earthworks Stage

In Alberta's oil sands mining, there are two types of deposit extractions: in-situ extraction and surface mining open pit (ERCB 2009).

To reach oil sands deposits by surface mining, the overlaying layers of topsoil, subsoil and overburden materials are removed and stockpiled to be used in reclamation operations later on. As mentioned previously, provincial and federal regulations request oil sands companies to do land reclamation after disturbing the land, to reach a state of "equivalent land capability" to the pre-disturbance land state (Harris 2007).

Generally, reclamation consists of re-establishment of soil and re-vegetation after mining works are finished. Usually the purpose of re-establishment of soil, also called earthworks, is to re-grade, stabilize and reshape the disturbed mine area for post-mining land uses. Re-vegetation slows down earth erosion, and assists in recovering the ecological system of the disturbed area. Usually, earthwork operations are very significant in any reclamation process; hence, it is very important to plan them well.

1.2.4 Planning for Reclamation Earthwork Operations

Currently in Alberta, a spreadsheet tool is used by the construction industry to model earthwork operations planning. According to personal interviews with

some Alberta superintendents working for Graham (2011), the planning procedure of reclamation earthwork operations is first to specify the excavating/placement locations, volumes of dirt to excavated and hauled. Second, excavators are allocated and matched with the appropriate truck fleet according to excavators and trucks capacities. Third, estimating how much time and volume one trip would take, then the productivity, number of trips, and project duration and cost can be estimated.

Using a spreadsheet tool to model the project can be problematic due to its over simplicity, so this approach requires highly experienced and skillful engineers and specialists. It is unable to take into consideration waiting time, equipment breakdowns, queuing effect, work locations, soil profile, and other aspects such as weather and working calendar all at once. The spreadsheet approach thus requires the use of many assumptions, is highly dependent on manufacturer's equipment tables and charts, and it is time and effort consuming.

This approach creates several issues. Testing of many scheduling scenarios is difficult with this approach. The approach also prevents the planner from plotting plans on a microscopic/detailed level, in which the planner can control the excavator/truck/dozer cycles. Another interesting point is the limited impact of the dozers' role in models using this approach.

This dilemma is a good candidate for computer simulation. Although the application of computerization is still rare within the construction and mining industries, the computerization of earthwork operations planning would be a comprehensive approach to amend these deficiencies.

1.3 CONSTRUCTION SIMULATION

1.3.1 Definition and Limitations

Construction simulation is the science of modeling and designing a real construction process, and manipulating the model using a computer (AbouRizk et al. 2011). One of the major merits of construction simulation is the ability to examine different scenarios and designs by manipulating the sequence and criteria of work activities, and the specifications and allocation of resources.

Unfortunately, construction simulation is still not widely implemented within the construction industry, and is limited to the academic field, because most of the existing construction simulation tools require a large amount of simulation and programming language understanding.

1.3.2 Approaches for Construction Simulation

According to AbouRizk et al. (2011), the discrete event simulation (DES) interaction approach is adopted overwhelmingly by construction simulation tools. DES is a modeling collection of components of action events with specific timing.

Virtual travelers through the action events series add up the time of the event to the total time of the simulation, and change the properties of the objects. These virtual travelers are called entities. Figure 1.1 shows the process of DES.
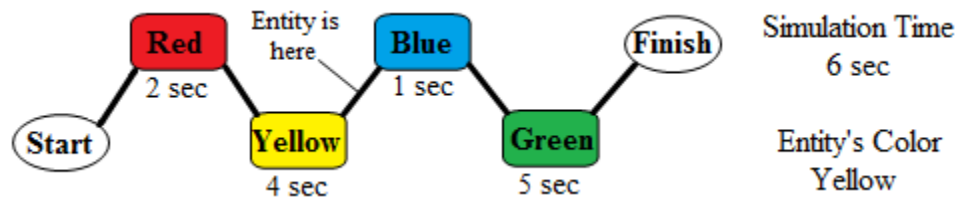
Figure 1.1 The DES Process

DES is useful when models are difficult to represent mathematically, can be developed to have a friendly user interface, and can act as a tool for specific construction applications (AbouRizk and Hajjar 1998). This type of tool is called Special Purpose Simulation (SPS).

The SPS is better-suited for practitioners since it takes very little time to learn, and it doesn't require a large amount of simulation or programming language knowledge. SPS application results in time reduction, as Nahrvar (2010) states "industry can train staff more quickly and implement this approach in a smaller timeframe, thereby making it more desirable to incorporate it in routine operations."

1.3.3 Simphony.NET

Based on the previous production of some SPS tools, and approximately 10 years of research in construction simulation, Hajjar and AbouRizk (1999) came up with a new simulation tool called Simphony. Then, building on Simphony, AbouRizk and Mohamed (2002) developed Simphony.NET. The modeling environment of Simphony.NET adopts the DES approach and is composed of a library of integrated objects called modeling elements. These elements are dragged and dropped in the modeling area, and connected to simulate a construction operation. Each element represents an entity creator, construction activity, resource, or entity flow organizer or tracker, and is able to produce custom output results visualized as tables and/or graphs.

Simphony.NET supports a very significant feature, the hierarchical modeling technique, in which, according to Hajjar and AbouRizk (2002), some modeling elements act like a container to some other modeling elements developed for this purpose. In other words, modeling systems contain sub-modeling systems of specific relations and properties. The modeling element containers are called "parents" and the contained elements are called "children" (Hajjar and AbouRizk 2002). The relationships and properties of children-parents, parents-parents, and children-children elements are defined by the developers. The hierarchical feature is very useful to model complex and comprehensive construction operations.

Simphony.NET uses general purpose simulation (GPS) to model construction operations using process interaction concepts. Though this type of simulation requires adequate simulation background, it is still achievable for practitioners. In addition to GPS, Simphony.NET supports the development of SPS templates for specific construction operations such as earthmoving and tunneling (Hajjar and AbouRizk 2002).

1.4 RESEARCH OBJECTIVES

The primary objective of this research is developing new practical and efficient simulation tool specifically for modeling the earthwork operations of the reclamation process. By incorporating simulation to manipulate the layout of the reclamation earthwork operations, encapsulating different activities and equipment all at once, the tool is capable of forecasting and controlling the productivity of equipment, duration of the project or activity, quantity of material processed, and project and equipment costs.

The research's primary objective will be achieved through the following objective categories: the objectives of simulation in general, and the earthwork operations simulation objectives.

1.4.1 Simulation Objectives

The main simulation objective is to develop a new Special Purpose Simulation (SPS) template using Simphony.NET 4.0 to model earthwork operations of reclamation. In addition, some other Simphony.NET features are developed:

1) Integrating Microsoft Access database with Simphony.NET 4.0 by incorporating Ms Access files into Simpony.NET and extract data to use it as input.

2) Enhancing visualization through inclusion of 2D-grid integration with different colors that changes according to the simulation progress. Also, adding percentage counters for simulation performance runs, and illustrating the output in spreadsheets.

3) Modeling the resources input data as input lists, each list represents a piece of equipment.

1.4.2 Reclamation Earthwork Operations Simulation Objectives

The purpose of the reclamation earthwork simulation is to develop an SPS template for the following sub-objectives:

1) Modeling the interactions between the equipment needed for reclamation earthwork operations; stripping dozer-excavator, excavator-truck, and truck-spreading dozer all together, but in the same time, allowing the modeler to deal with the input and output of each equipment piece separately.

2) Providing and visualizing the equipment results related to the equipment in the form of cycles, and making results information system almost identical to the data information system obtained from the equipment Vital Information Management system (VIMs) in the real projects. This also allows the modeler to track down the equipment, allowing for better control.

3) Allowing practitioners/modelers to incorporate historical data input along with the manufacturer standards charts and tables at the same time.

4) Allowing practitioners/modelers to estimate traveling time through mathematical formulas or through empirical/assumed speed data.

5) Providing the ability to manipulate the project's layout scenarios by allowing the modeler to use multi source and placement locations within the same model and with the same resources.

6) Incorporating the dirt material specifications and type, as well as the hauling road specifications and speed regulations during excavating and hauling operations.

7) Preserving the soil profile's structure during placement operations.

8) Including equipment breakdowns and fixing, waiting/queuing time, short breaks (availability on site), and general traffic interruptions.

9) Making the reclamation template flexible enough for the modeler to manipulate some excavation and placement criteria so it may eliminate the soil profile order preservation and hence to be used for general earthmoving operation purposes.

1.5 THESIS ORGANIZATION

In Chapter 1, a general understanding of reclamation earthworks and construction simulation is introduced, including brief description for reclamation's regulations, definition, earthwork phase, and planning; construction simulation's definition and approaches; and Simphony.NET's description. The objectives of this research are also presented.

Chapter 2 presents the literature review of construction simulation; definition, types and tools, and earthmoving simulation; objectives, requirements and tools, and reclamation earthworks planning; and criteria and tools.

Chapter 3 explains the reclamation process; activities and planning of reclamation earthwork operations; planning, activities, types and specifications of equipment involved; and types and specifications of dirt involved.

Chapter 4 presents the methodology that is used in the research by explaining the reclamation template in detail. It discusses elements: description and specifications; resources: types, description, specifications and interaction; and visualization: layout, output, reporting, and hierarchy.

Chapter 5 shows a real-life case study to examine the reclamation simulation template, analyzes the results, and discusses models for validation then illustrates

a comparison of the results and capabilities between the reclamation template and

the General Purpose Template of Simphony.NET.

Chapter 6 summarizes the research conclusions along with research contributions

and recommendations for future research.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses the state of art in literature on construction simulation, earthmoving simulation, and reclamation earthworks planning. First, the simulation definition, types, tools, and validating limitations are explored. Second, earthmoving simulation objectives and requirements, and earthmoving operations tools are given. Third, reclamation planning is explained, and the tools for earthworks planning methods are described.

2.2 SIMULATION

2.2.1 Simulation in General

Computer simulation software is used essentially for decision-making support, which saves costs and enhances efficiency (Klingstam and Gullander 1999). Computer simulation developed in conjunction with computer development. In the 1940s, a group of scientists including Neumann, Ulam, and Metropolis, were involved in the Manhattan Project that took place in Las Alamos Scientific National Laboratory for nuclear weapon research (Metropolis and Ulam 1949). During the Manhattan Project, the three scientists created the Monte Carlo Simulation method, which they later computerized (Metropolis 1987). This

achievement founded the way for more computerized simulation techniques, including construction simulation.

In the construction industry, construction simulation is a very efficient tool for operations optimization, equipment deployment, and selection to control and monitor cost, time, and production rates.

During the preliminary phase of a project when no data, such as cost, resource information, machine cycle times, and productivity is present, construction simulation is highly beneficial (Kannan et al. 1997). Construction simulation evaluates and investigates different scenarios by manipulating resources and work criteria and characteristics, so that a range responses, output, and results can be obtained (Han et al. 2005).

2.2.2 Discrete Event Simulation (DES)

To understand the advantages and outcomes of the construction scenarios, and because of the repetitiveness of construction activities, Discrete Event Simulation (DES) is an appropriate candidate to model construction operations (Mohsen et al. 2008). Construction operations are considered complex operations, because they are difficult to validate. DES is suitable to model and analyze such complex operations (AbouRizk and Hajjar 1998; Rekapalli and Martinez 2011).

According to Nahrvar (2010), DES adopts the basic simulation structure and depends primarily on stochastic algorithms, which, in time-discrete steps, DES is described as a current of discrete virtual objects (entities), streaming separately between activities. The model status changes only at time-discrete points (Andradottir et al. 1997).

The layout of DES is basically a network of activities that are implemented by the flow of the entities in a specific sequence, in which this sequence is predesigned by the modeler (Nahrvar 2010). There are two types of entities: internal entities and external entities. Internal entities are processed internally by the simulation software, while external entities are controlled and organized by the modeler (Andradottir et al. 1997).

2.2.3 Special Purpose Simulation (SPS)

Most of the construction simulation software generations are based on the General Purpose Simulation (GPS) concept and afford abstract and general modeling of construction operations which requires the practitioner to have considerable knowledge of DES. Hence, the concept of Special Purpose Simulation (SPS) was developed (Palaniappan et al. 2007). SPS is a domain-specific simulation tool that transforms domain knowledge into modeling elements to build and simulate domain-specific models (AbouRizk and Hajjar 1998). The key concepts of SPS-based tools include: domain specific modeling constructs that offer a high degree of resemblance between simulation model representation and real world

construction objects, hierarchical simulation concept, flexible interface visualization, and a suitable results format for the modeler (Hajjar et al. 1998).

2.2.4 State of Art Literature of Simulation

CYCLONE (Halpin 1973) was the first GPS tool used to model construction operations by using activity cycle diagrams (ACDs), visualizing oriented simulation and modeling elements to design different scenarios. CYCLONE inspired most of the current DES work, and many software generations of General Purpose Simulation systems have been developed afterwards, such as: INSIGHT (Kalk 1980); RESQUE (Chang 1986); UM CYCLONE (Ioannou 1989); COOPS (Liu 1991); CIPROS (Odeh 1992), which implemented object-oriented simulation environments; STROBOSCOPE (Martinez 1996), which enhanced the flexibility and extensibility of simulation modeling; EZStrobe (Martinez 1998); SIMPHONY (Hajjar and AbouRizk 1999), which utilizes a unified modeling methodology, and the ability to create special purpose models for construction operations; and Simphony.NET (AbouRizk and Mohamed 2002), which is a modeling environment to design the simulation model using a group of icons representing construction resources and resource stream route indicators. Also inspired were SDESA (Lu 2003; Lu et al. 2007), which improved the ACD simulation technique, and proposed the disposable resources concept; Simphony.NET 3.5 (AbouRizk and Hague 2008); and COSYE (AbouRizk and Hague 2009), which was developed based on the High Level Architecture (HLA) standards.

Additionally, there have been many developments for SPS tools for specific construction operations. For example, for earthmoving operations, there are some simulation tools such as AP2-Earth (Hajjar and AbouRizk 1996), EarthMover (Martinez 1998), and SimEarth (Marzouk and Moselhi 2003). Also, Simphony.NET (AbouRizk and Mohamed 2002) provided a number of SPS templates such as earthmoving, tunneling, aggregate production, pert, and crane templates.

2.2.5 Validating Limitations of Construction Simulation

DES has been developed and enhanced; however, the construction simulation model validation requires improvement because it still faces some critical problems (Robinson 2005). The construction simulation development, along with the validation development, is necessary to improve the overall model development process.

2.3 EARTHMOVING SIMULATION

No simulation software or programs have been developed specifically for reclamation earthworks. Previously, modeling of reclamation earthwork simulation scenarios was attempted through GPS software or general earthmoving SPS software. For the aforementioned reason, and since the activities and resources of the reclamation earthwork operations are similar to the general

earthmoving operations, the state of art in literature of the earthmoving operations simulation should be discussed.

2.3.1 Earthmoving Simulation Objectives and Requirements

Like reclamation, Cheng et al. (2011) realized that earthmoving is a complex operation of a discrete event nature that is influenced by many factors such as workflow and information flow. They (Cheng et al., 2011) also stated that "Based on the number of available equipment, characteristics and parameters of equipment, construction management principles, main factors and information about related cost, the simulation model of earthmoving operations is capable of predicting operation situations of earthmoving construction, equipment productivity, and the estimated completion time and cost". By predicting such aspects, the earthmoving operations simulation primary objectives, such as enhancing equipment selection range and productivity, and minimizing project duration and cost, would be achieved. In ideal use of equipment, when appropriate equipment is selected, the productivity is maximized; hence, the contractors' profit is maximized, which means that projects are finished within the planned project duration with minimum costs (Reda, 1990).

2.3.2 State of Art Literature in Earthmoving Simulation

To achieve the objectives mentioned in the last section, numerous simulation methods have been developed to forecast earthmoving operations performance.

Queuing theory is commonly used method for designation of the earthmoving simulation model.

Halpin and Woodhead (1976) implemented queuing theory for earthmoving operations; Hrebar and Dagdelen (1979) developed a simulation model for selecting dragline stripping equipment; MicroCYCLONE (Halpin and Riggs 1992) evaluated different fleet scenarios; Shi and AbouRizk (1994) analyzed strip mining construction using simulation to estimate the minimum equipment unit cost; AP2-Earth (Hajjar and AbouRizk 1996) developed an SPS template specifically for earthmoving operations, giving the practitioner the domain to build different modeling scenarios to get output and results statistics; EarthMover (Martinez 1998), Mather and AbouRizk (1999), and Xu (2001) integrated construction simulation with CAD and implemented that in earthmoving operations to improve the accuracy of the excavation operation; CAES (Caterpillar 2001) was developed to maximize the production of dozers; and SimEarth (Marzouk and Moselhi 2003) used the object-oriented simulation concept and Genetic Algorithm (GA) to optimize the earthmoving operations. Hegazy and Kassab (2003), Cheng and Feng (2003) and Cheng et al. (2005) presented simulation by combining GA with CYCLONE or other simulation concepts. Zhang et al. (2004) combined DES concept and fuzzy logic to eliminate the fuzziness in the duration estimation of construction operations. Bargstädt and Blickling (2005) presented an IT system that considers fleet teams, and models real time scenarios with a graphical interface. Van Tol and AbouRizk (2006)

proposed a resource allocation model for earthmoving operation. Moselhi and Alshibani (2007) proposed a system along with spatial technologies to control and plan earthmoving operations. Prata et al. (2008) proposed the Petri nets method to model the earthmoving process stochastically. Zhang (2008) proposed a particle group optimization algorithm to find out possible configurations of equipment.

All the previous tools have contributed to the state of art and the construction/mining industry regarding earthmoving. However, the earthworks operations of reclamation have a particular distinction that the placement procedure and dirt material stockpiling and distribution are based on the demand to keep the placed soil profile layers order the same as pre-disturbance state, so previous tools are not sufficient for use in simulating these situations.

For example, some of these existing tools include CAES (Caterpillar 2001), which deals with dozers individually to maximize their production, regardless of the purpose of the activity performed by the dozers, or the interaction between them or neither the overall fleet. However, EarthMover (Martinez 1996) deals with fleet but focuses on selecting the best truck fleet scenario and on choosing the best path; also, the truck fleet is not broken down into different units, hence, the output does not reflect the production of each equipment piece. Similarly, AP2-Earth (Hajjar and AbouRizk 1996) considers earthwork operations activities such as loading trucks, placement of dirt (spreading and dumping), but still considers the trucks as the model's entities, and the soil profile structure

specifications have limited impact over the operation activities and the output. Finally, SimEarth (Marzouk and Moselhi 2003) deals with fleet optimization via cost and time optimization, and it visualizes the results for each equipment piece, but it does not consider the placement criteria or assigning equipment to a specific soil layer which represent another core difference between reclamation earthworks and general earthmoving operations.

2.4 RECLAMATION PLANNING

2.4.1 Reclamation in General

Traditional mine planning primarily considered removing soil and overburden material and extracting the ore. Reclamation planning used to be a secondary or lowest priority issue, but since the 1990s, reclamation execution and planning have been necessary in Alberta, both environmentally and economically (McKenna 1996). In general, the primary objective of reclamation planning is to develop the best method of reclaiming a mine site, in which it is technologically feasible and economically achievable. To achieve this objective, McKenna (1996) mentions 15 new concepts that have been developed in Alberta for reclamation planning: "Defining closure goals, designing for closure, use of landforms and natural analogs, self-armoring bouldery ground, robustness in design, landform grading, terrain analysis of reclaimed land, geotechnical hazard assessments, choices in closure design timeframes, passive maintenance, determine post

closure monitoring goals, engineering tailings, engineering other substrates, use of test plots and field demonstrations, and visiting other mines".

Reclamation costs cover stabilizing and re-grading the land, constructing an appropriate ground cover, planting tree seedlings, any fines stemming from failure to meet the reclamation standards, and the resulting cost of redoing or making amendments (Sullivan and Amacher 2010). For stabilization, the overburden resulting from mining operations is used to reclaim the pre-mining contour of the disturbed land. Subsoil material (secondary) is placed over the overburden material and used for re-grading. Then topsoil materials (muskeg and litter, fibric and humic material (LFH)) are placed, establishing a ground cover. The operations mentioned previously represent the earthwork phase of the reclamation process. After the earthworks phase is done, the vegetation phase takes part to help the ecosystem to recover and enhance the sight view.

In the following chapter, the reclamation planning is discussed in more detail.

2.4.2 Earthworks Planning

Since the earthworks process is a major part of any reclamation project, developing a plan for earthworks is very important. The main objective for reclamation earthworks planning is to maximize the equipment optimization so that the overall operational cost and duration are minimized. The equipment productivity, according to Han et al. (2006), comes through the productivity

evaluation, by studying the activities sequence and the resources allocation using decision-supporting methods.

According to Burt et al. (2005), there are three main methods used widely in the mining industry for equipment allocation: Mining Method Selection (MMS), Equipment Selection (ES), and Shovel (Excavator) Truck Productivity (STP). For Shovel (Excavator) Truck Productivity method, the mining industry has traditionally used modeling methods such as match factor, bunching theory, and productivity curves (Burt et al. 2005). There are many equipment allocation methods such as simulation, integer programming, artificial intelligence, neural network, Petri-Nets, and spreadsheets. From personal interviews with some superintendents and experts working for Graham in Alberta (2011), and recent mining literature, spreadsheets are the most common method used in mining industry planning. In addition, the methods and approaches currently depend on the manufacturer equipment tables combined with manual calculations and estimates using historical data and/or rules of thumb (Kartam 1996). As a result, to develop successful earthwork plans, a very experienced and skillful engineer/specialist is required to invest information and interpret satisfying solutions.

In the following chapter, reclamation earthworks planning is discussed in more detail.

2.4.3 State of Art Literature in Earthworks Planning

Several earthworks equipment selection methods with different modeling approaches have been developed to obtain suitable earthwork operations plans.

Naoum and Haidar (2000) tried to plan equipment selection, including the cost of a machine's official lifetime from manufacture to retirement, using artificial intelligence. Karshenas (1989) obtained some enhancements involving the queuing theory method in equipment selection. Jayawardane and Harris (1990) prioritized earthwork operations completion time for estimating fleet size using integer programming. Amirkhanian and Baker (1992) used artificial intelligence for equipment selection, creating approximately 1000 rules, which incorporate earthmoving activities, soil state, and operator skills. Huang and Kumar (1994) developed a model to optimize the earthmoving equipment fleet size using queuing theory method. Also using integer programming, but with a different highest priority, Cebesoy et al. (1995) applied budget constraints to specify equipment fleet size. Kartam (1996) integrated the spreadsheet method with the Artificial Neural Network (ANN) approach for equipment selection, specifically for the dozer/scraper fleet, incorporating the hauling road conditions. Burt et al. (2005) developed a model for equipment fleet selection incorporating equipment cost using an integer linear program and compared the results with ones of linear match factor method modeled through spreadsheets.

Based on personal interviews with superintendents and experts working for Graham (2011), the mining industry in Alberta implements a mix of match factor and integer programming methods modeled through spreadsheets, by matching trucks with excavators, then estimating the time and load capacity of one truck trip. The average productivity and the necessary number of loads to complete the project are determined.

The literature of some simulation methods used for earthwork operations planning is discussed in detail in the previous section.

CHAPTER 3 THE EARTHWORK PROCESS OF RECLAMATION

3.1 INTRODUCTION

This chapter discusses reclamation planning in general, reclamation earthworks planning, and the process of reclamation earthworks. First, reclamation planning's importance, concepts, objectives and general practices are explained. Second, reclamation earthworks planning's importance, approaches, and current planning practices in Alberta are given. Third, reclamation process's operations, soil material handled, and components are discussed.

3.2 RECLAMATION PLANNING

3.2.1 The Importance of Reclamation Planning

Reclamation is important for many reasons, including human quality of life and resource investments. Reclamation is fulfilled when sustainable development is guaranteed through the integration of development strategies with environmental policies. In the mining sector, as discussed in previous chapters, the integration of development strategies with environmental policies can be achieved through well planned and monitored reclamation. Good reclamation planning results in achieving the reclamation goal, which is defined by Rajaram et al. (2005) as "the establishment of a stable and self-sustaining ecosystem that will, in time, re-create

a productive and suitable ecosystem that will replace the pre-mine ecosystem and achieve the desired post-mining land use."

McKenna (1996) describes three reasons why reclamation planning is important. Firstly, reclamation is costly; hence, planning can help prevent large expenses. Secondly, changing the regulatory environment. Thirdly, if any failings occur in mandating the environmental performance, companies' owners and/or managers could be prosecuted by law.

In addition to that, according to EPEA (Conservation and reclamation regulation (2) 2010), the reclamation of the land must be consistent with the directions, terms, criteria, and guidelines of the Director. The mine operator must obtain a mining permit, for which the application must include the duty of the reclamation operations. Thus, the mine operator is in charge of developing the reclamation plan within the regulations' constraints.

In any reclamation plan, there should be "a balance between environmental performance, mine economics, and residual liability, with the aim of responsibly returning the land to the Crown," states McKenna (1996). In other words, the planning system of reclamation must consider objectives that are technically possible, economically achievable, and committed to the performance standards; which, according to Sullivan and Amacher (2010), are a primary component of

the reclamation planning process, because they are the basic judgment rules for successful reforestation.

3.2.2 Concepts and Criteria of Reclamation Planning

Successful planning is important to avoid the consequences of poorly planned performance standards. Unnecessary ''private cost'' which may occur when these standards are beyond meeting the protection needed (Sullivan and Amacher 2010). Syncrude Corporation developed some new concepts for planning the mine closure in Alberta in the mid 1990s. McKenna (1996) lists these concepts: "Defining closure goals, designing for closure, use of landforms and natural analogs, self-armoring bouldery ground, robustness in design, landform grading, terrain analysis of reclaimed land, geotechnical hazard assessments, choices in closure design timeframes, passive maintenance, determine post closure monitoring goals, engineering tailings, engineering other substrates, use of test plots and field demonstrations, and visiting other mines".

The following are brief clarifications of some of the concepts involved in reclamation planning that are outlined by McKenna (1996):

1) Closure goals: The most important component in planning is formulation of goals.

2) Designing for closure: Closure design provides an evaluating data system for decision makers. Early reclamation design is beneficial because it is more

flexible to amendments or changes, saves time and costs, reduces liabilities, and facilitates reclamation bonding release.

3) Landforms and natural analogs: This strategy is a powerful tool in reclamation. Natural analog requires knowledge of natural systems, mine economics, and geomorphic stability. It predicts the mining landform's performance.

4) Bouldery ground: Bouldery ground means shielding the streams naturally with boulders and aggregate. This process only needs trucks, and hence, the cost is low.

5) Robustness: Robustness means that a land recovers itself or is redundant.

6) Landform grading: Landform grading minimizes erosions and increases land stability.

7) Terrain analysis: Terrain analysis is a system that is applied to pre-mining and reclaimed land that characterizes the reclaimed area's changes using digital terrain modeling (DTM), and a geographic information system (GIS), along with a database.

8) Geotechnical hazard assessment: This assessment evaluates the geotechnical hazards and risks, such as slope stability issues, erosion, and contamination.

9) Closure design timeframes: Closure design timeframes consider environmental regulatory conditions and the hazards involved. The timeframe can be specified by historical engineering performance along with assessments of erosion rates, contamination, and other risks, with the possibility of considering several timeframes for different risks.

10) Passive maintenance: Passive maintenance is applicable in long-term, low-risk and low-cost cases, and can be covered by maintenance bonds. In the case of long-term, high-risk activities such as acid rock drainage (ARD) or water treatment, active maintenance is required.

11) Post-closure monitoring goals: Some criteria and aspects should be monitored regularly for the reclaimed areas; for example, biological stability, erosion, groundwater, and others. The post-closure monitoring period will be minimized if the design takes robustness into consideration.

12) Engineering tailings: McKenna lists three methods of engineering tailings: "water-capped fluid fine tails lakes; composite tailings; and freeze-thaw-dewatering fine tailings". The first method has slow consolidation. The latter two have faster consolidation, but with more contaminant fluxes.

13) Engineering other substrates: By separating waste substrates, the concentration of the containment efforts would differ according to the hazardous degree of such substrates. Also, substrates can be used for vegetation control.

14) Test plots, field demonstrations, and monitoring: Test plots help in verifying different reclamation strategies. Continuous monitoring helps identify potential issues in early stages of the mining period. Field demonstrations help to increase the confidence of all the parties involved in the post-closure process. All in all, they provide technology exchange between research and other sectors.

15) Visiting other mines: Visiting mines within the same area, or working under the same regulations offers useful information. It also ensures that information, research, and technologies are exchanged. In addition, reclamation is not performed for each mine separately or independently.

Some additions from Rajaram et al. (2005) refine the concepts mentioned above:

1) Site investigation: It is necessary to collect data for human health, ecological risk assessment, and studying reclamation alternatives. Studying reclamation alternatives would consider: the quantities of the containment sources, containment concentration, re-vegetation parameters, and soil characteristics. The risk assessment consists of four steps: hazard identification, exposure assessment, toxicity assessment, and risk characteristics.

2) Creating reclamation alternative scenarios: The reclamation plan should create different alternative scenarios, ranging from no reclamation at all to full reclamation. The following criteria should be considered: protection of human health and the environment, regulations and requirements, long- and short-term effectiveness, toxicity reduction cost, and practicality. In addition to these criteria, the following components should also be considered: economics, technical issues, environmental condition, and location.

3.2.3 Reclamation Objectives

Reclamation planning has to take the disturbed mine land uses into consideration. Hence, determining the best use(s) is a big challenge to the reclamation planner, who will plan reclamation. To reach satisfying reclamation planning objectives and have a successful reclamation project, Rajaram et al. (2005) sees that there should be consensual determination and strong collaboration between the mine operators, government authorities, and local communities (the public), from the planning phase through to the end of the reclamation works. The mine operator's main interest is to minimize the reclamation cost and cover the performance standards (Sullivan and Amacher 2009).

In such collaboration and land use objectives, three issues must be considered: environmental issues in which redevelopment should be compatible with the environmental remedy for the site; economic issues that address the challenge of the funding sources whether they are Federal or Provincial government grants, or a third-party benefited from site and finally, regulatory issues including collaboration with the authorities (Rajaram et al. 2005).

3.2.4 Reclamation General Practices

Before plotting and executing any reclamation techniques, the mine type should be specified. The following are brief clarifications of general reclamation techniques described by Rajaram et al. (2005):

A) Coal mining: reclamation practices differ according to the mining method. The first mining method is area mining method, used when the mining zone is flat and the mine operator can reclaim the post-mining land directly. Contour mining is used on hill sides and reclamation is executed to a specific contour. Mountain-top mining is used in mountainous areas and the reclamation is done by filling the valleys with overburden material.

B) Non-coal mining: Usually in non-coal mining, these reclamation practices are applied:

1) Reclamation zones: Specify the mine areas to be reclaimed; these are usually are divided into the pit, waste disposal areas, and the surface plant.

2) General techniques:

- Barriers and shields: Sight borders and lines should be established in the planning phase. Disruptive views are hidden or covered by a permanent barrier such as landscaping and vegetation barriers.

- Pit slopes: The pit slopes of the reclaimed area should be as close as possible to the natural slopes in that area. That may includes bench removal.

- Pit boundaries: Usually the reclamation mine plan begins from the center of the pit land, and then moves to reach the boundaries.

- Water: Some pits may be reclaimed as a lake or pond.

- Waste piles: Usually for structural and aesthetic features, any reclamation plan should ensure that the waste piles look natural and do some vegetation on the surface.

- Other considerations: There are other options such as backfilling.

3) Land use: The reclamation plan should offer flexible post-mining land use, taking into consideration how the adjacent land is being developed to be used. In the case of land rehabilitation, the interaction between the public and the mine operators and reclamation staff should be continuous to ensure social and economic satisfaction.

3.3 RECLAMATION EARTHWORKS PLANNING

3.3.1 The Importance of Reclamation Earthworks Planning

Earthworks of any project represent a considerable percentage of the overall project cost and duration, and reclamation projects are not an exception. Hence, developing a reclamation earthworks plan is very important. The ultimate objectives for reclamation earthwork operations planning are to enhance productivity/production to minimize cost and time, and to achieve the best post-mining conditions of a disturbed land. According to Han et al. (2006), an optimized earthwork plan requires the planners to verify the productivity of different planning scenarios, including the activities' sequence, and the resource

allocation. Earthwork resource allocation and appropriate equipment selection are significant components of the plan. The primary goal for any earthwork plan for equipment selection is to select trucks, excavators, and dozers, so that the queuing time is reduced and equipment performance optimization will be maximized, hence, the overall operational cost and duration of the earthwork operations are minimized and the productivity is maximized (Burt et al. 2005). As a result of good equipment deployment planning, the operation performance is more efficient, which leads to, as Naoum and Haidar (2000) mentioned, huge savings and highly optimal solutions earthwork operations scenarios.

3.3.2 Earthworks Equipment Selection Approaches

Smith et al. (2000) acknowledges that currently, the industry practices three methods used for the equipment selection. These three methods are: the Mining Method Selection, Equipment Selection and Excavator-Truck Productivity.

Burt et al. (2005) combined and clarified these different methods involved in equipment selection process along with the accompanied modeling tools. The following are brief clarifications of these methods mentioned by Burt et al. (2005) excluding simulation and the artificial intelligence modeling tools:

A) Mining method selection: This method allows the environmental and geological conditions to control the selection of equipment; the mining method is specified based on the environmental and geological conditions,

and consequently, this mining method will recruit equipment selection. Excavators fleet size and type are chosen according to the excavation conditions and requirements, then trucks fleet size types are selected according to the excavator choices, and then the dozers fleet size and type are chosen according to excavators and trucks selection.

B) Equipment selection: This method selects equipment sets according to the work objectives and constraints. There are many methods that can be applied in equipment selection such as:

1) Integer programming: Integer programming concentrates on project constraints rather than methods, including constraints such as time (project duration), cost (project budget), or, according to Celebi (1998), truck loads or passes between excavators and trucks.

   When these constraints are set in the model, the equipment types will then be selected or assumed along with the fleet size. Integer programming has been used in mining and construction areas; however, it is criticized for its excessive use of assumptions and simplifying the selection process.

2) Simulation: This method is widely used to model mining and construction operations. Especially in analyzing the earthwork operations, Cheng et al. (2010) acknowledge that simulation is able to forecast the activity status, equipment productivity/production, and the operation's cost and duration,

given the equipment selected (types, fleet size and characteristics), and other management aspects (activities cost, time and sequence).

In addition, simulation is capable of verifying the current equipment selection and suggesting alternative equipment selections to achieve the optimum selection scenario. As it is discussed in previous sections, earthwork operations, including equipment selection, are modeled as discrete event simulations (DES), due to the dynamic nature and the uncertain circumstances involved.

3) Artificial intelligence: Artificial intelligence methods like fuzzy logic, expert systems, genetic algorithms, and neural networks have been used in equipment selection and construction planning previously. Artificial intelligence is constructed to implement and incorporate human knowledge and expertise in a modeling tool (Welgama and Gibson 1995). These methods are usually used when project constraints become nonlinear due to some aspect such as queuing, risks, scope changes, etc. (Burt et al. 2005).

C) Excavator-truck productivity: This method is based on the prediction of excavator and truck productivity to select equipment (trucks and excavators) types and fleet size. Morgan and Peterson (1968) argue that the most important prediction is the trucks' travel times and the interaction significance between the excavators and trucks.

1) Match factor: This method is based on the assumption that the most productive equipment selection (types and fleet size) equals the most economical fleet. This indicates equipment fleet suitability and efficiency in an operation. The match factor can be done through simple calculations and diagram plotting.

2) Bunching theory: Bunching models capture the tendency of moving objects to bunch together when moving in a line. This method is usually useful when some equipment is performing work more than other equipment. This work variation naturally occurs in equipment work cycles due to queuing and other unpredictable delays. These time adjustments, which reduce the ability of a fleet to work within its performance capacity, are called bunching.

3) Queuing theory: This method considers equipment queuing issues such as lengths, waiting times, and other aspects. Queuing theory method uses the arrival time of the coming piece of equipment into an activity, instead of the entire fleet, hence, the equipment's productivity and project estimations depend highly on how well the times between arrivals are assumed or estimated. This method is used in a lot of construction estimating tools such as simulation and artificial intelligence.

The classical methods for equipment selection in earthwork planning are the match factor, bunching theory, and productivity curves.

3.3.3 Current Industry Practices of Earthworks Equipment Selection in Alberta

Usually the aforementioned classical methods are modeled using a spreadsheet tool. At least in reclamation earthwork planning, spreadsheets highly depend on the planner's experience, skills, and knowledge of technical conditions of the project. In addition, earthwork spreadsheet planning uses equipment manufacturer standards tables and charts, possible assumptions, and sometimes historical data to make different estimations. Hence, most of the estimation of different times, material quantities, and productivity are performed by "rules of thumb" (Kartam 1996). As a result, most of the time, reclamation earthworks planning is time and effort consuming, and the chances of achieving a credible plan are doubtful.

Based on an example of a reclamation earthwork spreadsheet planning project, and according to interviews with superintendents working for Graham (2011), the planning procedure simply consists of the following:

- Define specific areas of cut with the quantity of material that needs to be excavated, the dump location, with the possibility of dividing the areas of excavation and/or placement into smaller areas or blocks (polygons) to increase accuracy.

- Specify the average required depth and volume of the placed material.

- Estimate how many truck loads are required by dividing the volume of the material that needs to be excavated by the truck's overall capacity.

- Match the excavators with the trucks according to the capacities of both, then estimate loading time by dividing the excavator's overall capacity by the truck's overall capacity, and then multiply the result with the average single load of the excavator's bucket.

- Estimate hauling time by dividing the distance by the speed of the full truck, and return time by dividing the distance by the speed of the empty truck. The total travel time is the combination of hauling time and return time.

- Estimate overall traveling time for all trucks by multiplying travel time of a single truck with the number of trucks.

- Combine the overall travel time with the overall loading time of all trucks to find the project duration.

- The production of a truck is estimated by dividing the truck's total travel time by the total material hauled by that truck.

- The cost of each equipment piece can be estimated by multiplying the time performed by an equipment piece (trucks and excavators) with the accompanied unit rate.

- The total project cost is the summation of the equipment costs.

Regardless of its credibility, although the aforementioned procedure seems easy and simple since it depends on assumptions such as total resistance and soil

specifications, and manufacturer's tables and charts, the process might take a couple of weeks as it is very difficult to incorporate different truck/excavator types, because it is very simple for modeling earthwork operations which are unique and involve many factors, and also it lacks the flexibility which makes difficult to try different allocation scenarios.

3.4 RECLAMATION EARTHWORKS PROCESS

After discussing the planning of the earthwork process, the process of the reclamation earthwork operations must be discussed, including the activities and operations, the soil material processed, and the components including equipment, site, and hauling route conditions, etc.

The following sections are a combination of assembled knowledge learned from different resources, and general facts about the earthwork operations. The equipment equations and information, and the material equations were taken from Peurifoy et al. (2010), Nunnally (2007), and the Caterpillar Performance Handbook (2010). All of the information about the reclamation earthwork process was learned through study of reclamation projects documents from Graham (2011), and personal interviews with superintendents working for Graham (2011). The haul route (road) section was developed by the researcher based on the equations of motion in simple physics and some aspects of transportation engineering such as altitude and stopping sight distance.

3.4.1 Operations Involved

Typically, the earthwork process consists of the following operations: excavating, loading, traveling, and placing. The traveling operation consists of hauling and returning operations, and the placing operation consists of dumping, spreading, and compacting operations. However, the main difference in the earthwork operations of reclamation is that the placing consists only of dumping and spreading operations.

An extremely important point is that the placement of the dirt must be in a specific order, conditioned with preserving the original soil profile and structure that existed before the excavating operation.

The equipment used in the aforementioned operations should be chosen according to the work scope and conditions, in addition to the specifications of the dirt material handled. For example, the size and/or type of the excavator used for topsoil material removal could be different from that used for subsoil material removal due to the layer thickness and possible obstructions found within the soil layer, also, the size and/or type of the excavator used in one location could be different from that used in another location due soil specification difference and obstructions existence that may vary from a location to another.

The equipment used for excavating will be discussed in the following section because it depends on the type of the dirt material. For loading operations, loaders and excavators are used. For traveling operations, trucks, dozers, scrapers, and loaders can be used depending on the traveling distance. For spreading operations, dozers, scrapers, and graders are used. For compacting operations, soil compactors are used.

Some minor operations would be added to the reclamation earthwork process taking place in Alberta: snow removal and clearance, ditching, and road maintenance. First, snow should be removed at the beginning of the earthwork operations, and constantly removed during the process. Usually, motor graders, tractors and dozers are used for snow clearing throughout winter. Second, ditching the area should be done to drain the water table, and then salvaging starts. Third, sometimes maintaining and grading the haul routes throughout the earthwork operations may be considered as part of the reclamation project depending on the project contract and scope of work. This is usually performed using motor graders and scrapers.

In this research, only the equipment used specifically for reclamation earthwork processes in Alberta in the current time will be considered. Therefore, the excavators will be considered for excavating and loading operations, trucks will be considered for traveling operations, and dozers for excavating (stripping the topsoil) and spreading operations. Additionally, the aforementioned minor

operations will not be considered because their significance on the reclamation process is relatively minimal.

3.4.2 Soil Material Handled

The soil material processed in any earthwork operation usually contains at least one of the following: topsoil, subsoil, and the overburden material. The topsoil material consists of two layers of material: litter, fibric and humic material (LFH), and the muskeg material. The subsoil material consists of one layer of material called the secondary material (clay, sand and/or silt). The overburden material is usually consists of bedrocks and sediments mixed possibly with clay material.

As mentioned in the previous section, the main distinguishing point of the earthwork process of reclamation is to preserve the soil profile when placing the soil material. In other words, the topsoil material must be placed above the subsoil material, which must be placed above overburden material. That means secondary material is placed first, above the overburden, then the muskeg material is placed above the secondary material, and finally the LFH material is placed above the muskeg material. If there is nowhere to place a specific type of soil material, due to this rule, that type will be dumped and stockpiled temporarily in another location, and reloaded and hauled again to the required placement site. For example, if the placement site has only secondary material placed, no LFH material will be placed; hence, it will be stockpiled temporarily in a different location, and reloaded and hauled back to the original site. This process will add

to the original cost and duration of a project, and this addition could be significant.

The first excavation operation is the excavating of the LFH material. This process should be done during summer (when the weather is warm); however, LFH should be loaded, hauled, and placed in winter, and then spread in summer. Dozers are used for the stripping, and excavators are used for truck loading.

After LFH removal, excavation of the muskeg material commences in winter to freeze the water table close the surface. The muskeg material is excavated, loaded, hauled, and placed during winter, and then spread during summer. Since muskeg removal occurs in winter, the snow should be cleared off first, taking into consideration that clearing off the snow is a continuous process throughout winter. Afterwards, ditching the area should be done to drain the watertable, and then salvaging starts. Usually, dozers are used for the stripping, and excavators are used for truck loading.

After that, the excavation of the secondary material takes place. Typically, excavators are used for both the excavation and the truck loading.

3.4.3 Components

The main components of any earthwork process, in general, and related to reclamation specifically, are: the working sites, haul routes (roads), and

equipment. The equations in the following sub-sections represent typical and traditional procedures used by construction/mining industries, which can also be substituted by different approaches such as neural networks, fuzzy logic, and others. Measuring unit compatibility must be considered and checked in the equations presented in this section, keeping in mind that the measuring units are not included in the equations in this section.

3.4.3.1 Working Sites

The working sites are the excavation sites, which are the source of the soil material. The placement sites are the final destination of the material. Both excavation sites and placement sites cover the soil material's types and specifications. The parameters required to understand the soil material's specifications and to estimate the dirt quantities (volumes and weights) are the bulk and loose volumes, the bulk density, the payload, and the swell factor (Peurifoy et al. 2010, Nunnally 2007, and Caterpillar Performance Handbook 2010). These parameters affect the earthwork process scope significantly.

The dirt's bank volume and density are the volume and density when the dirt is in a natural state before excavation. The dirt's loose volume is the volume when the dirt is in the disturbed state due to movement after excavation, and before stockpiling if compaction is required in the stockpiling process. The payload is the actual weight of dirt that fills a container such as the bucket of an excavator or

a truck. The swell factor is the factor to transform the density and volume from loose state to bank state and vice versa.

The bank volume and density and swelling factor can be obtained through field tests and geotechnical surveys performed on site that requires reclamation, while according to Peurifoy et al. (2010), Nunnally (2007), and Caterpillar Performance Handbook (2010), the payload and loose volume can be obtained through the following calculations:

$$Loose\ volume\ =\ bank\ (volume)\ \times\ (1\ +\ swell\ factor)............(1)$$

$$Payload\ =\ bank\ volume\ \times\ bank\ density.............................(2)$$

The bank and loose volumes will be used in the production calculations of the different equipment. The payloads will be used for some of the truck calculations such as maximum speed and the TKPH.

3.4.3.2 Haul Routes

The haul routes represent the roads of the working sites. One haul route could include several road segments, and each segment has different specifications such as length, grade and speed limits. The parameters required in order to measure the roads' impact on the speed of the truck are the rolling resistance (RR), the grade resistance (GR), the total resistance (TR), the altitude factor, the weight of the truck, and the turn radius and superelevation if the road segment is curved

(Peurifoy et al. 2010, Nunnally 2007, and Caterpillar Performance Handbook 2010).

The RR is the force that must be overcome to roll a wheel over the ground, while the GR is the force that must be overcome to move a machine over a certain slope road. When uphill, GR has a positive sign, and a negative sign when downhill. The altitude is the actual percentage of power/speed performance on a certain altitude.

The RR, GR, TR, altitude factor, turn radius, and superelevation can be obtained through field tests, historical data, or hauling route geometric design drawings, while the TR is the combination of the RR and the GR, multiplied by the altitude factor. The truck's weight is equal to the empty weight (manufacturer's standards) plus the payload obtained from equation (2) which the bank volume parameter will be truck's capacity (struck or heaped) in bank state. The maximum speed of a truck can be estimated through Caterpillar charts by matching the TR with the weight of the truck, or through assumptions, or historical data. In the curved segments, maximum allowable speed on a curve is specified using the standard tables such as those in the Caterpillar Performance Handbook (2010), by matching the turn radius with the superelevation; the minimum of the two speeds (allowable and trucks speed) will be adopted for speed maximum limit in the calculations.

The typical and traditional approaches to estimating the traveling time are either using average speed values or functions regardless of road events (stopping, accelerating, decelerating, etc.), or considering the road's events using the basic physics formulas of motion. The first method is the empirical method and the second is the mathematical method. As it is mentioned previously, some other approaches can be used to estimate traveling time; however, in this research, these two methods are used for traveling time estimation.

In the empirical method, the travel time is estimated just by dividing the road's length by the speed function. However to estimate traveling time through the mathematical method, the following basic equations of motion are used in ideal conditions:

$$V_f = V_i + (at)\dots\dots\dots\dots\dots(3)$$

$$D = V_i t + \frac{1}{2} at^2 \dots\dots\dots\dots\dots(4)$$

$$V_f^2 = V_i^2 + 2aD\dots\dots\dots\dots\dots(5)$$

Where,

V_f: final speed (km/hr).

V_i: initial speed (km/hr)..

a: acceleration (km/hr^2).

D: distance (km).

t: time (hr).

In the mathematical method, the parameters required to estimate the traveling time are number of road segments, segment length, stopping sight distance (SSD), the distance for the truck to reach the maximum speed (Dvmax), the truck's speed, and the acceleration.

The number of road segments, segment length, stopping sight distance (SSD), and the distance to reach the maximum speed for a truck (Dvmax) can be obtained by field tests, assumptions, or historical data, while the truck's speed can be obtained as it is described previously.

Using the aforementioned information, the acceleration (a) can be estimated via equation (5), considering V_f to be the average truck's maximum speed of all road segments, V_i is zero since the truck starts traveling after loading or dumping activities, and D is the distance to reach the maximum speed (Dvmax).

To estimate the traveling time considering the given parameters, there are two cases:

A) Single segment:

Figure 3.1 shows travel time estimation for a one segment haul route.
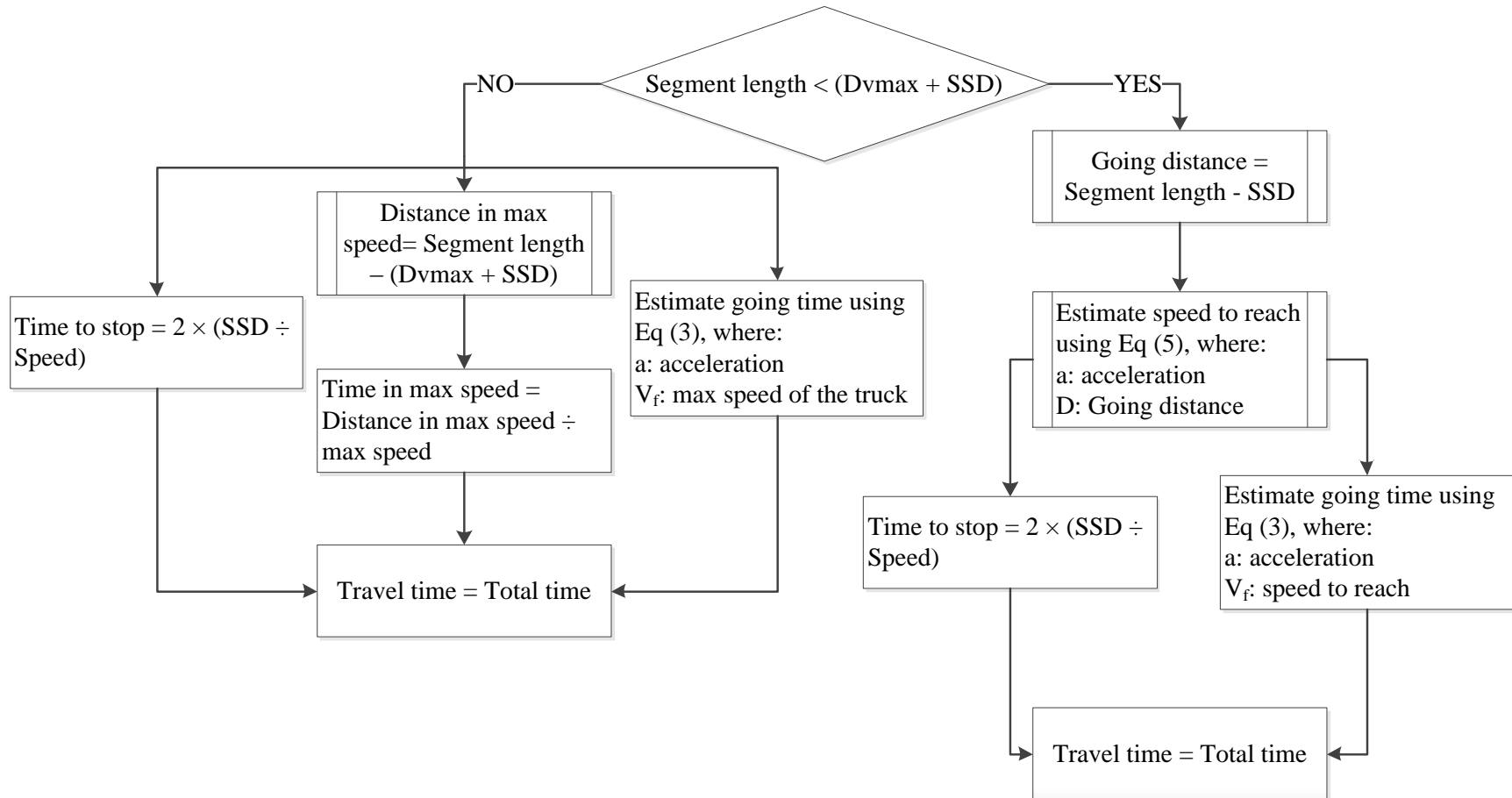
Figure 3.1 Travel time estimation for a one segment haul route

B) Multi segments:

1. First Segment: Figure 3.2 shows travel time estimation for the first segment of a multi segments haul route.
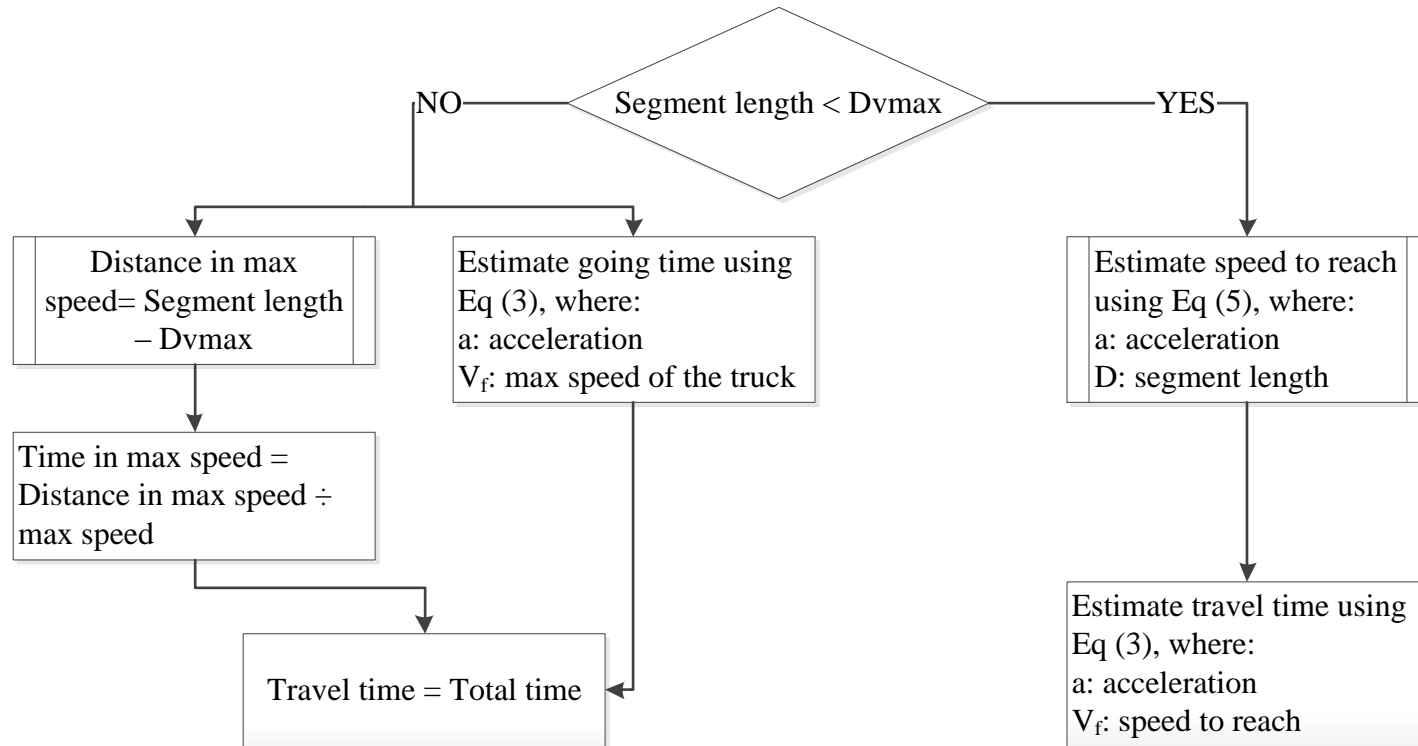
Figure 3.2 Travel time estimation for the first segment of a multi segments haul route

2. The following segment: Figure 3.3 shows travel time estimation for any segment in the middle of a multi segments haul route.
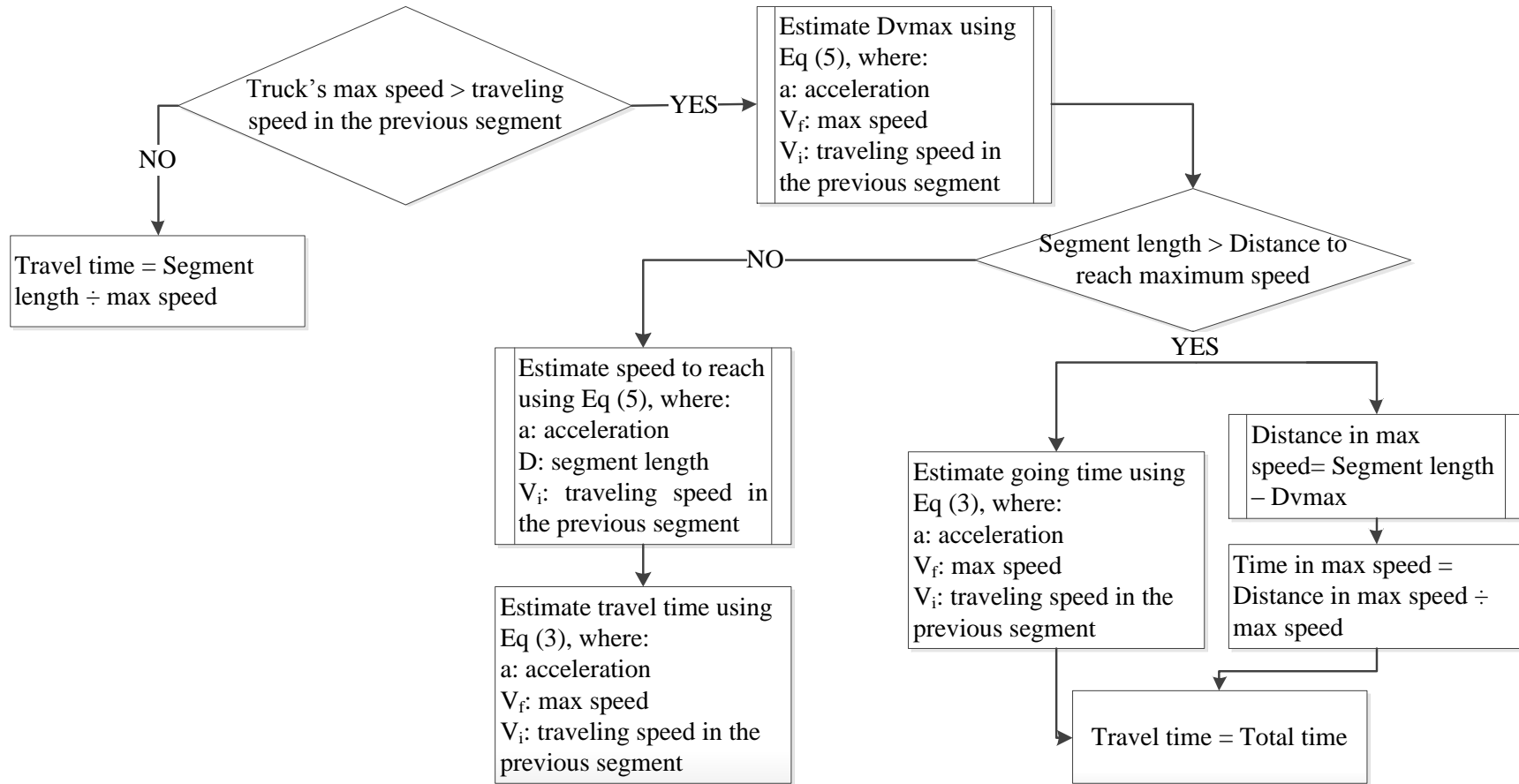
Figure 3.3 Travel time estimation for any segment in the middle of a multi segments haul route

3. Last segment: Figure 3.4 shows travel time estimation for the last segment of a multi segments haul route.
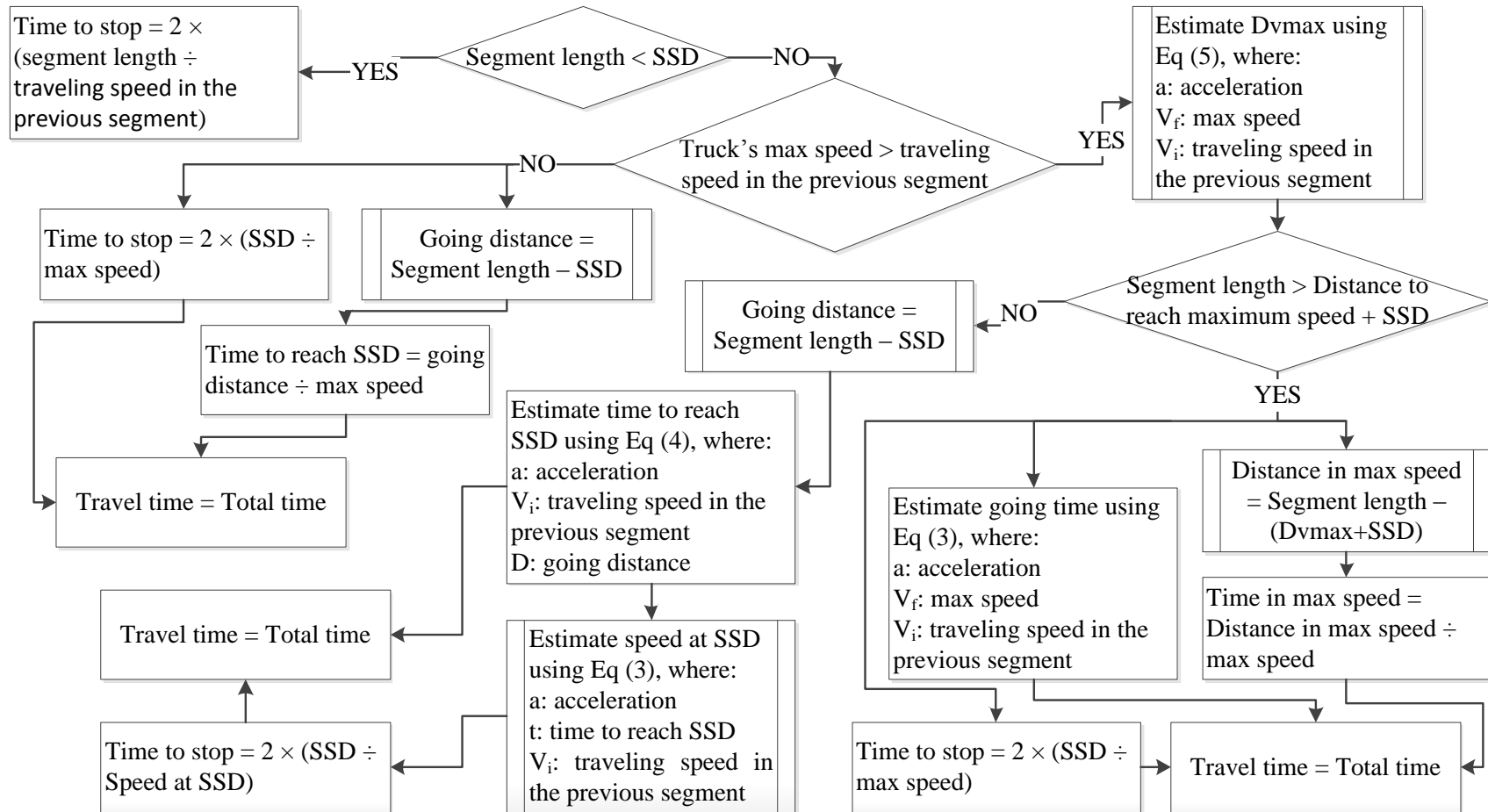
Figure 3.4 Travel time estimation for the last segment of a multi segments haul route

3.4.3.3 Equipment

As mentioned previously, in this research and according to the actual earthwork processes of reclamation in Alberta, the equipment involved includes excavators, trucks, and dozers. The most important aspect to estimate for equipment is the production, which is the volume of dirt handled in a specific amount of time. Typically, and according to Peurifoy et al. (2010), Nunnally (2007), and Caterpillar Performance Handbook (2010), the equipment's production (m^3/hr) is estimated through the following equation:

$$Production = \frac{BV \times E}{T} \dots\dots\dots\dots\dots(6)$$

Where,

      BV: the bank volume of dirt processed (m^3).

      E: equipment's efficiency.

      T: equipment's working time (hr).

Efficiency is the actual working time in minutes per sixty minutes. In other words, how much time the equipment practically works when it is available on site. For example, if the daily shift of a truck is 8 hours then practically it is working 6 hours (after ommitting coffee breaks, site meetings, miscellaneous breaks, etc.). So, the efficiency will be 0.75 (45mins/60mins). It is important to note that queuing (waiting) and breakdowns make the equipment unavailable on site, hence, they are not counted in efficiency loss (difficiency).

3.4.3.3.1 Excavators

Excavators are used for excavating the secondary material and loading all of the dirt material into the truck. Excavators type and specifications. The parameters required to estimate the production of the excavators are the heaped capacity of the bucket, the fill factor, the average angle of swing, the maximum digging depth, the percentage of depth of cut, the swing-depth factor, loading time, number of cycles and the efficiency (Peurifoy et al. 2010, Nunnally 2007, and Caterpillar Performance Handbook 2010).

The swing-depth factor is a reduction factor to combine the effect of digging depth along with swinging angle. The cycle time is the time consumed to perform the following activity only once: loading, swinging with load, dumping and swinging in return. The fill factor usually depends on the material type and the bucket size and type.

The bucket heaped capacity, bucket fill factor for specific soil material, and maximum digging depth can be obtained from the manufacturer's tables, while the cycle time, average angle of swing, and the efficiency depend on the project conditions and can be obtained through field tests, assumptions, or historical data.

The percentage of depth of cut results from the ratio of the actual digging depth to the maximum digging depth. Then, swing-depth factor can be obtained through manufacturer's tables by matching percentage depth of cut with the average swing

angle in the table provided. The number of cycles can be estimated by matching the excavator's bucket capacity with the truck's capacity. Then the loading time is estimated by multiplying the cycle time by the number of cycles.

The general equipment production estimation that is illustrated in equation (6) is adjusted for the excavator's production estimation, in which, according to Peurifoy et al. (2010), Nunnally (2007), and Caterpillar Performance Handbook (2010), equation (6) is multiplied by the swing-depth factor and the fill factor. The working time of the excavator will be the loading time. Therefore, the resulting production (m^3/hr) equation is:

$$Production \ = \ \frac{BV \times E \times SD \times F}{L} \ \dots\dots\dots\dots\dots(7).$$

Where,

    BV: the bank volume of dirt processed (m^3).

    E: efficiency.

    L: loading time (hr).

    SD: swing-depth factor.

    F: fill factor.

3.4.3.3.2 Trucks

The trucks are used for transporting (hauling) all of the dirt material to the truck. They cover the trucks' types and specifications. The parameters required to

estimate the production of the trucks are the heaped capacity, dumping time, loading time, working time, and the efficiency (Peurifoy et al. (2010), Nunnally (2007), and Caterpillar Performance Handbook (2010)).

The working time is the time consumed to perform the following activities: loading, travelling, and dumping. The heaped capacity can be obtained from the manufacturer's tables, while the efficiency and dumping time depend on the project conditions and can be obtained through field tests, assumptions, or historical data. The travel time and loading time are obtained as stated in hauling route section.

The general equipment production estimation illustrated in equation (6) according to Peurifoy et al. (2010), Nunnally (2007), and Caterpillar Performance Handbook (2010), is valid to estimate the truck's production, with adjustments.

Another interesting aspect regarding the trucks is the effect on the tires, expressed as the ton-km-per-hour (TKPH). The parameters required to estimate the production of the trucks are the empty weight of the truck, the payload, the percentage of weight distribution empty (front, rear), and loaded (front, rear), the number of front and rear tires, the weight on individual front tire (empty or loaded), and the weight on individual rear tire (empty or loaded) (Caterpillar Performance Handbook 2010).

The empty weight of the truck, percentage of weight distribution empty (front, rear), and loaded (front, rear), and the number of front and rear tires can be obtained from the manufacturer's tables, while the payload is obtained from equation (2), and hence, the weight of loaded truck the empty truck weight plus the payload. According to Caterpillar Performance Handbook (2010), the weight on individual front tire (empty or loaded) results from multiplying the percentage of weight distribution empty or loaded (front) by the weight of the truck (empty or loaded) divided by the number of front tires, while the weight on individual rear tire (empty or loaded) results from multiplying the percentage of weight distribution empty or loaded (front) by weight of the truck (empty or loaded) divided by the number of front tires.

Also, based on Caterpillar Performance Handbook (2010), the TKPH for each trip is estimated through the following equation:

$$TKPH_{single\ trip} = AS \times Maximum\ value\ of\ (RTL, FTL)....(8)$$

Where,

      AS: the average speed; trip distance divided by working time (km/hr).

      RTL: average rear tire load in tons (average of when empty and loaded).

      FTL: average front tire load in tons (average of when empty and loaded).

Finally, the total TKPH is estimated as:

$$Total\ TKPH = \frac{\Sigma\ (TKPH)trip}{number\ of\ trips}...............(9)$$

3.4.3.3.3 Dozers

The dozers are used for stripping the topsoil material (LFH and muskeg) and spreading all of the dirt material to the truck. They cover the dozers' types and specifications.

A) Spreading dozers:

According to Caterpillar Performance Handbook (2010), the parameters required to estimate the production of the spreading dozers are the distance of spreading, correction factors (operator skill, material type, operating technique, visibility, machine transmission, efficiency and grade factors), and the ideal production which the production of soil material in loose state when ideal working conditions are present.

The distance of spreading depends on the project conditions and can be obtained through field tests, assumptions, or historical data, while the correction can be obtained from the Caterpillar Performance Handbook (2010) tables or assumptions. Spreading ideal production can be obtained through Caterpillar Performance Handbook (2010) charts by matching the type of the dozer and the type of the dozer's blade with the distance of spreading.

Unlike the production estimation of the excavators and trucks, the production of the spreading dozer is not estimated using equation (6), rather, it is based

on Caterpillar Performance Handbook (2010), estimated through the following equation for production (m³/hr) of soil in bank state:

$$Production = \frac{IP \times PCF}{(1 + SF)} \dots\dots\dots(10)$$

Where,

IP: ideal production (m³/hr) of soil material in loose state.

PCF: the product of the correction factors.

SF: swelling factor.

In order to estimate the actual production of soil material in bank state, the equation has to be divided by the swelling factor added to one (1).

B) Stripping dozers:

The parameters required to estimate the production of the stripping dozers are the average time to strip one meter square, the capacity of the dozer's blade, the area of the location required to be stripped, , and the efficiency.

The average time to strip one meter square, the area of the stripped location, and the efficiency depend on the project conditions and can be obtained through field tests, assumptions, or historical data, while the blade's capacity

can be obtained from the manufacturer's tables. Stripping time is estimated by multiplying the amount of area stripped by the average time to strip one unit area.

Finally, equation (6), which describes the equipment production estimation in general, is valid to estimate the stripping dozer's production.

However, according to interviews with superintendents working for Graham (personal communication, 2011), the suggested approach is adequate to the template's scope.

CHAPTER 4 RECLAMATION EARTHWORK TEMPLATE

4.1 INTRODUCTION

This chapter discusses the simulation special purpose template for reclamation earthwork projects using the Simphony.NET 4.0 software environment. First, the reclamation template's scope and structure are outlined. Second, the reclamation template's general procedure is explained. Third, the distinction of reclamation earthworks and simple earthmoving is given. Fourth, the template's elements are described. Fifth, possible modeling scenarios are outlined. Sixth, database integration and transformation of the Caterpillar charts into database templates is explained. And finally, manipulation of the template for use in general earthmoving purposes is explained.

4.2 RECLAMATION TEMPLATE'S SCOPE AND STRUCTURE

Reclamation projects require that earth layers be returned to their original condition during, or after, mining earthwork operations, whether at the same location (source and placement), or from one location (source) to another (placement). The reclamation template is a special purpose simulation (SPS) tool for designing, analyzing, and estimating the earthwork operations of the reclamation projects, after operations such as mining and construction. It consists of a number of elements through which a model for earthwork operations of the

reclamation can be defined and manipulated. Users are allowed to plan a number of earthwork operations' alternatives for a reclamation project.

The three main components of the special purpose template are: source, placement, and traveling. The source activities consist of excavating and loading, and the equipment used is the excavators and trucks. The placement activities consist of dumping, spreading, and stockpiling, and the equipment used is the dozers and trucks. And finally, traveling activities consist of hauling and return, and the equipment used is the trucks.

Using Simphony.NET 4.0, the entity of the template represents the dirt volume (soil quantities), in that it models dirt volume via a soil profile of three layers (LHF (litter, fabric, humic), muskeg, and secondary) and represents the soil's source and placement areas. The resources of the template represent the equipment, which includes the excavators, trucks, and the dozers, of which, the number, properties, and deployment of trucks, excavators, and dozers can be manipulated easily to examine their effects on production, activity time, quantities, operating cost, and reclamation rates. Users can also manipulate the road layout, and examine the effects of using different paths. Note that the cost of operation is primarily equipment costs. Figure 4.1 shows the reclamation template's scope and structure.

Entity (soil) flow

Soil to be excavated → Soil excavated per cycle → Soil hauled per cycle → Soil dumped → Soil spread per cycle → Time & Cost

Expectations

To Forecast, estimate and control:
1. Productivity of each equipment
2. Time for the project or package
3. Quantity of material excavated, hauled, stockpiled
4. Overall cost and equipment cost
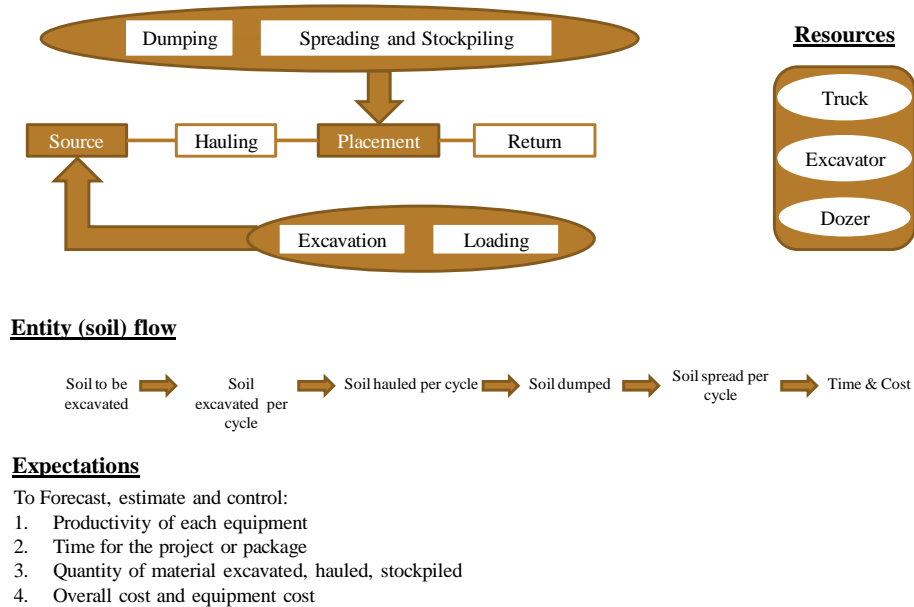
Figure 4.1 The reclamation template's scope and structure

4.3 GENERAL PROCEDURE

To create an earthwork reclamation model, first add the reclamation template (.dll) to the general purpose template by doing the following:

1) From the "Start" menu, select "All Programs."

2) Go to Simphony.NET 4.0, then select "Modeling Environment" to launch Simphony.NET.

3) From Simphony's "Home" menu, click on "Add Template."

4) Browse for the file of the template in program files:

- Open the "Simphony.NET 4.0" folder under program files.

- Open the "Template" folder.

- Select the reclamation template's (.dll) file.

The reclamation template will be added to the left-hand side of Simphony's user interface, below the "*simphony.general*" elements. Once the reclamation template has been added to the general template, drag and drop the template's elements from the left side of the screen onto the modeling surface as required.

Typically, when modeling a reclamation operation, the basic elements include: a source element (sends dirt), equipment elements (excavator, truck, and dozer), and a placement element (receives dirt). The stockpile and intersection elements are optional. All the elements, except equipment, can be connected by clicking on the element's outlet port, and moving the mouse curser to click on an input port of another element. The connecting line between the elements represents the road element (haul and return routes). The source and the placement elements are composite elements, each with a 2D grid layout representing either the excavation area (source), or the spreading area (placement). Both grids consist of a number of rectangular unit areas, each containing a soil profile.

Equipment can be assigned to each unit area, or to a soil layer in each unit area, depending on the equipment type. Excavators and trucks are assigned to soil layers in the source element, while dozers are assigned to unit areas in both the source and placement elements. The stockpile element is used to store dirt that

cannot be received by the placement(s) because of the fixed placing sequence of the soil layers. Multiple source and placement elements can be modeled in the template operating the same mutual equipment units. They can be connected via the intersection element.

A screen shot of a typical layout for a reclamation earthwork operation's model (left) and the reclamation template's modeling elements (right) are shown in Figure 4.2.
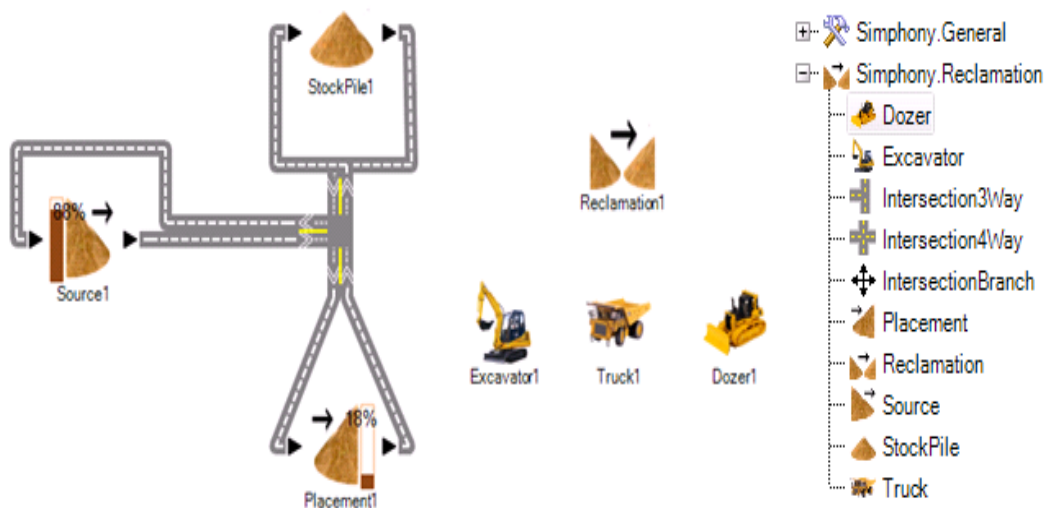
Figure 4.2 Typical model layout for a reclamation earthwork operation (left) and the modeling elements list (right)

To set up and run a reclamation earthwork operation model, follow these steps:

1) Drag and drop the source, truck, excavator, dozer, placement, intersections, stockpile, and reclamation elements into the user interface.

2) Connect the elements that have ports (source, placement, intersection, and stockpile).

3) Double-click on each element and enter its parameters.

4) Run the simulation and view the results, such as: equipment cycle output spreadsheets, equipment overall output, reclamation final results (volumes, reclamation percentage, time, cost, and production rates), tracing equipment breakdowns, equipment utilization and charts (output vs. cycles), and final report. Figure 4.3 shows a sample of charts, final report, cycle spreadsheet, and breakdown tracing.
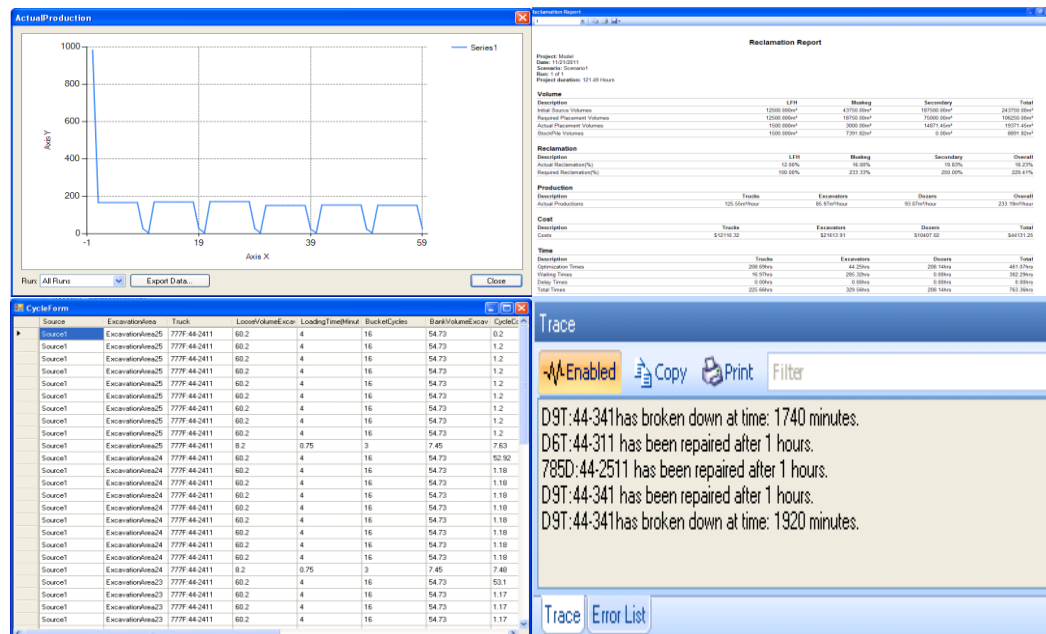
Figure 4.3 An example of the charts, final report, cycle spreadsheet, and breakdown tracing of a reclamation simulation

A detailed description of how inputs for each element are entered and their respective simulation behavior is presented in Section 4.5.

4.4 THE DISTINCTION OF RECLAMATION AND EARTHMOVING

Reclamation earthwork operations are very similar to normal earthmoving operations; however, a critical difference exists: in reclamation, the source's soil profile order MUST remain the same when it is placed. In the template, the soil profile is set to have two (2) topsoil layers: LFH (litter, fabric, humic) and muskeg, and one (1) subsoil layer: secondary. The natural sequence of these layers in the source area is: secondary at the bottom, muskeg in the middle, and LFH on top. This sequence must be conserved in the placement area. For example, if the existing layer in a placement area is rocks, then the secondary subsoil layer must be placed first, then muskeg, and then LFH. In other words, when a placement area is still in needed of secondary subsoil material, muskeg and LFH are not to be placed. Hence, they have to be dumped temporarily in a stockpile area, and then relocated to the placement area after placing sufficient secondary subsoil material. The stockpile element is made to represent the aforementioned temporary stockpile area for the dirt layers which cannot be placed at that moment. In this case, the stockpile element is NOT an optional element anymore. According to this discussion, this soil profile conservation issue has a significant impact on time, cost, production rates, equipment deployment, and reclamation percentages. As a result, it was realized that this must be taken into consideration in developing the reclamation template.

4.5 ALGORITHM OF THE TEMPLATE

Before starting to develop the template's components in details, a general template algorithm must be constructed to establish the base of understanding the template's logic and simulation process.

Basically, the simulation controller is the dirt quantities; the simulation keeps running until all sources are empty of dirt, then the simulation will be terminated and final output is obtained.

The reclamation template's algorithm consists of three levels; first level (L1) is the source algorithm. The second level (L2) is the activities involved in the dirt material processed. And finally the third level (L3) is the truck traveling activities along with dirt placement process. These three levels are connected to each others in a hierarchical form, in which, level one (L1) encapsulates level two (L2), and level two (L2) encapsulates level three (L3).

Figure 4.4 shows the source algorithm (L1), Figure 4.5 shows the activities involved in the dirt material processed (L2), and Figure 4.6 shows the truck traveling activities along with dirt placement process (L3).
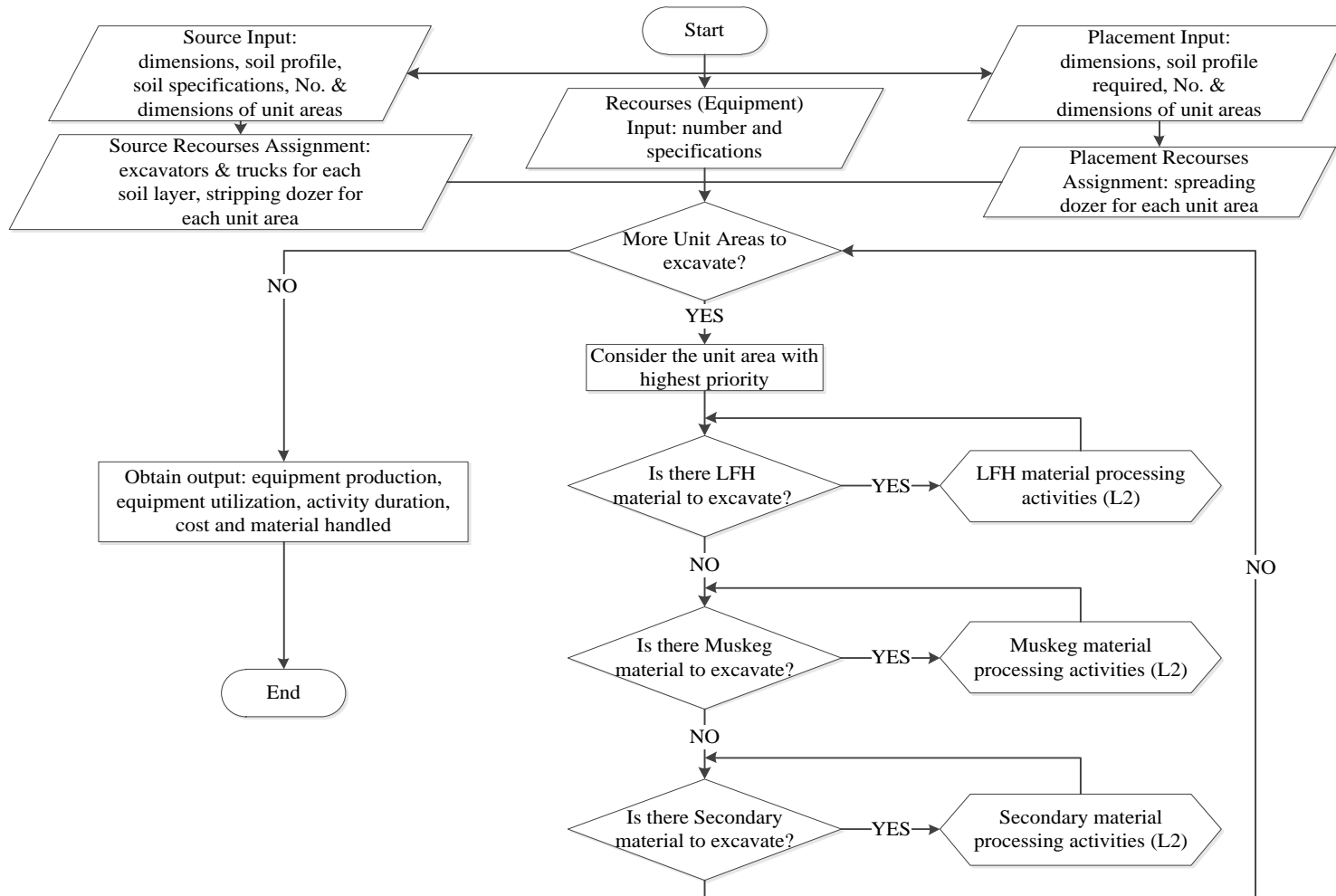
Figure 4.4 Source algorithm (L1)
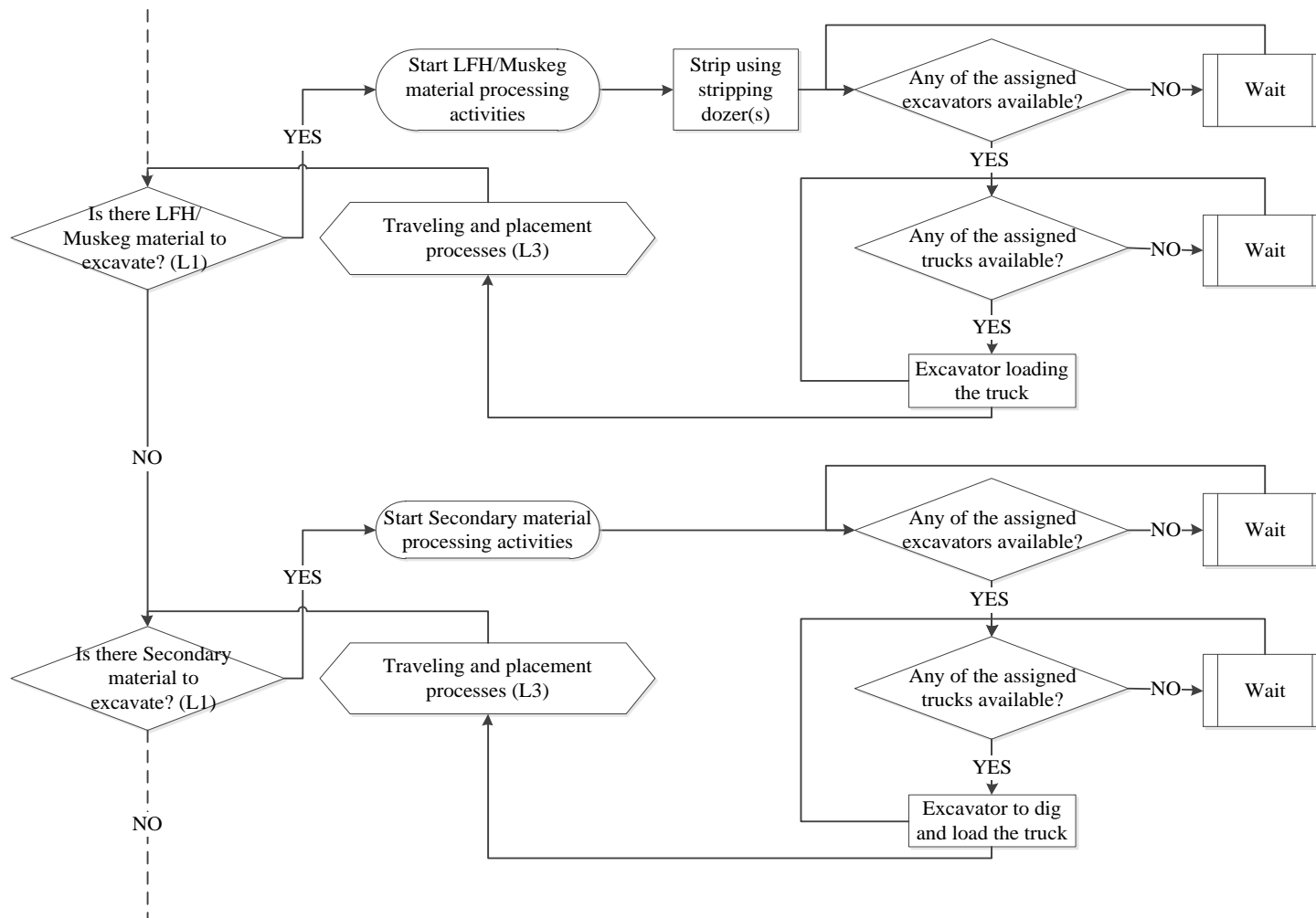
Figure 4.5 Activities involved in the dirt material processed (L2)
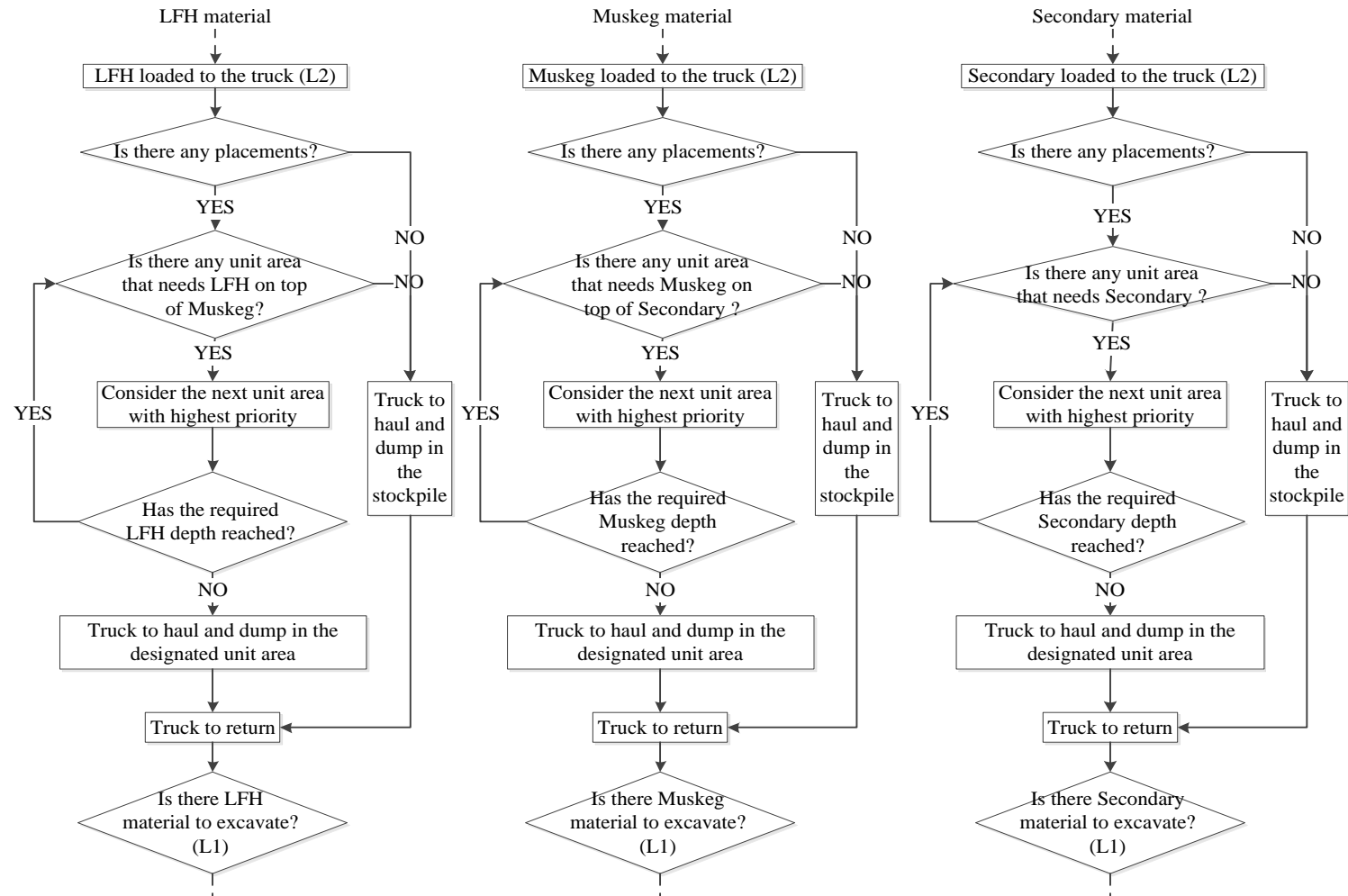
Figure 4.6 Truck traveling activities along with dirt placement process (L3)

4.6 ELEMENTS OF THE TEMPLATE

There are ten (10) elements of the template: source, placement, truck, excavator, dozer, stockpile, roads, intersections, branch, and reclamation.

Some of these elements are resources that do not hold or carry the entities. These resources are truck, excavator, and dozer. Other elements are the destinations of the entities. These elements are source, placement, and stockpile. One reporting element is reclamation, one virtual element is the roads, and one child element is the branch that can only be used inside the intersection element. Figure 4.7 shows the element icons of the template (also illustrated in Figure 4.2).
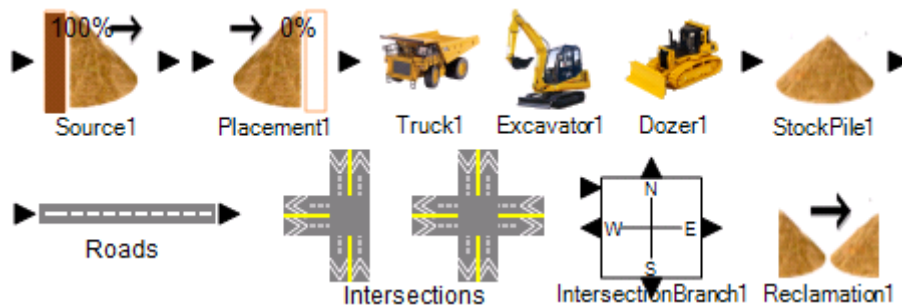
Figure 4.7 The element icons of the template

In order to develop these elements using the Simphony.NET 4.0 environment in a way that ensures the aforementioned scope is met and incorporates the information and logic described in the rest of the chapters (particularly that presented in Chapter 3 and Chapter 4 section 4.5), services of a professional

programmer specialized in programming languages such as C#, visual basic, C++, etc., have been appointed.

4.6.1 Source Element

The source element represents the site from which earth is taken. It connects to placement elements, intersection elements, or stockpile elements. At least one source element should be created in the simulation model.

The source element contains a default 2D grid model of rectangular area units. Double-clicking on an area unit opens up the soil profile (LHF, muskeg, and secondary layers) and equipement lists (excavators and trucks) for each layer. The user chooses which unit areas to excavate, and the sequence of excavation. Table 4.1 shows the input and the output of the source element.

For each area unit, the user:

- Assigns an excavator element, a truck element, and a dozer element.
- Chooses one or more excavators and trucks for each soil layer.
- Chooses one or more stripping dozers for the area unit.

The choices of excavators, trucks, and dozers will be limited by what each element consists of. Figure 4.8 shows a sample 2D grid layout and soil profile inside the source element.

Note that the distance between the unit areas (X and Y directions) is taken into account in estimating the hauling and returning distances. This distance estimation is modeled to consider that the truck comes to the top left corner to start loading.

Also, the unit area's color changes during the simulation, based on the unit area of highest depth (green) and lowest depth (red); a unit area goes green when its depth becomes the highest on the 2D grid, and goes red when its depth becomes the lowest, or becomes zero.

Table 4.1 The input and the output of the source element

General Input	- Width of a Unit Area (m) - Length of a Unit Area (m) - No. of Units Within X-axis - No. of Units Within Y-axis - Site Condition (for maneuvering time estimations) - Entry Area	- Exit Area - Swell Factor of LFH Layer - Density of LFH Layer (kg/m^3) - Swell Factor of Muskeg Layer - Density of Muskeg Layer (kg/m^3) - Swell Factor of Secondary Layer - Density of Secondary Layer (kg/m^3)
Unit Area Input	- Depth of LFH Layer (m) - Depth of Secondary Layer (m)	- Depth of Muskeg Layer (m) - Priority (the higher priority the earlier to be excavated)
Output	- Remained Depth of LFH (m) - Remained Volume of LFH (m^3) - Remained Depth of Muskeg	- Remained Volume of Muskeg (m^3) - Remained Depth of Secondary (m)

	(m)	- Remained Volume of Secondary (m^3)
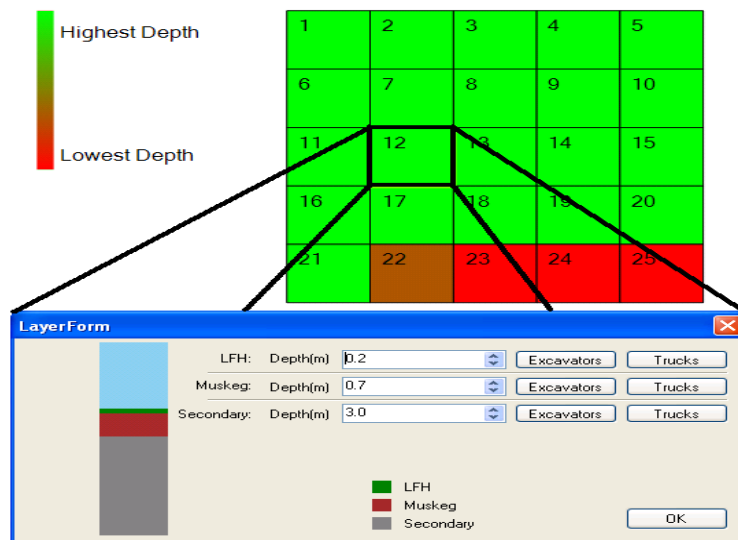
Figure 4.8 A sample 2D grid layout and soil profile inside the source element

4.6.2 Placement Element

The placement element represents the final destination of the dirt. It connects to the source or intersection elements. At least one placement element or one stockpile element should be created in the simulation model.

The placement element contains a default 2D grid model of rectangular area units. Double-clicking on an area unit pops up the soil profile (LHF, muskeg, and secondary layers). The user chooses which unit areas to spread and the sequence of spreading. Table 4.2 shows the input and the output of the placement element.

For each area unit, the user:

- Decides which layer to place and spread first in each unit area by specifying the existing layer before running the simulation.

- Assigns a dozer element for spreading.

- Chooses one or more spreading dozers in the element.

The choice of the dozers is limited by what the elements consist of. Figure 4.9 shows a sample of a 2D placement grid and soil profile inside the element.

Note that the distance between the unit areas (X & Y directions) is taken into account in estimating the hauling and returning distances. This distance estimation is modeled to consider that the truck comes to the top left corner to start loading.

The unit area's color changes during the simulation based on the unit area of highest depth (green) and lowest depth (red): a unit area goes green when its depth becomes the highest depth of the 2D grid sheet, and goes red when its depth becomes the lowest, or becomes zero.

Table 4.2 The input and the output of the placement element

General Input	- Width of a Unit Area (m)	- Entry Area
	- Length of a Unit Area (m)	- Exit Area
	- No. of Units Within X-axis	- Site Condition (for
	- No. of Units Within Y-axis	maneuvering time estimations)

Unit Area Input	- Required Depth of LFH (m) - Depth of Existing Layer (m) - Type of Existing Layer	- Required Depth of Secondary (m) - Required Depth of Muskeg (m)
Output	- Placed Depth of LFH (m) - Placed Volume of LFH (m^3) - Placed Depth of Muskeg (m) - Placed Volume of Muskeg (m^3)	- Placed Depth of Secondary (m) - Placed Volume of Secondary (m^3) - Total Depth (m) - Total Volume (m^3)
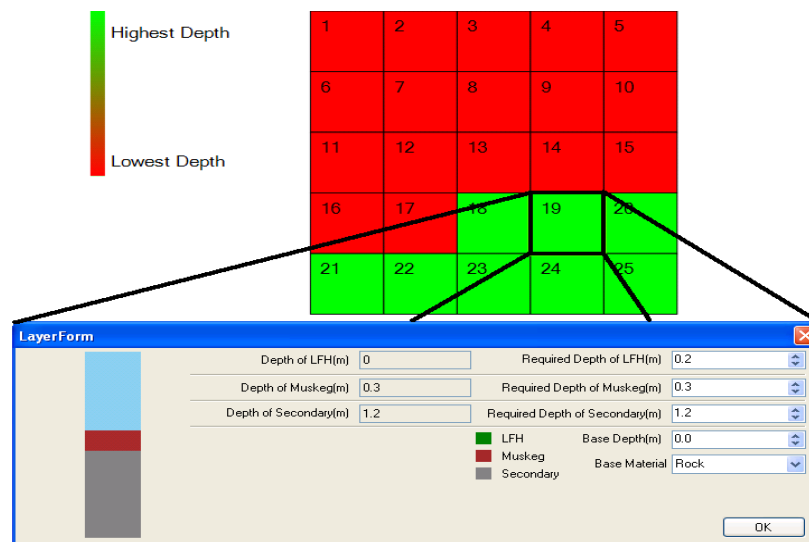
Figure 4.9 A sample 2D grid layout and soil profile inside the placement element

4.6.3 Resource Elements

The resource elements contain the equipment that can be used in the template. The template's equipment elements are the excavator element, the truck element, and the dozer element. The user specifies the number of each type of equipment, and each of the equipment's specifications and parameters. Each element has a list of available equipment; each row in the list displays the equipment's name,

properties, and output. The name of an equipment unit is a unique parameter that cannot be repeated, otherwise an error message pops up and the simulation refuses to run. The unit name combines an ID number with the equipment type.

The total working time of a unit equals the time of optimization, waiting, and delay. Optimization and waiting times are discussed in each equipment definition. The equipment's delay time is the time, other than waiting, that the machine is not performing any work (usually it is being fixed). It is obtained via simulation. Efficiency is the actual working time in minutes per sixty minutes. In other words, how much time the equipment practically works when it is available on site. For example, if the daily shift of a truck is 8 hours then practically it is working 6 hours (after omitting coffee breaks, site meetings, miscellaneous breaks, etc.). So, the efficiency will be 0.75 (45mins/60mins). It is important to note that queuing (waiting) and breakdowns make the equipment unavailable on site, hence, they are not counted in efficiency loss (deficiency). Equipment breakdowns are modeled by specifying the time between breakdowns. As soon as a unit begins operating, breakdowns start to be taken into consideration.

There are three types of production rates: maximum production, normal production, and actual production. Maximum production is the quantity processed (m^3) within a certain time, when waiting time and delay time are excluded. Normal production is the quantity processed (m^3) within a certain time when

delay time is excluded. Actual production is the quantity processed (m^3) within the total working time.

The output is classified into two types: cyclic output and overall output. The cyclic output is the result obtained for each processing cycle, and can be shown via spreadsheets. Overall output is the result after the equipment is done operating. Some cyclic output, such as actual production, normal production, maximum production, bank volume processed, cost, optimizing time, delay time, and waiting time, is shown via charts (parameter vs. cycle number).

Some of the input parameters are modeled as Probability Distribution Functions (PDF). The PDF abbreviation will be included in the decription of an input parameter, if it is modeled as a Probability Distribution Function.

4.6.3.1 Truck Element

A truck is assigned to a dirt layer in a source element. The truck cycle starts when a truck comes to a unit area, and finishes when the truck returns to either the same unit area or to another one. The truck leaves when its capacity is full or when no quantities are left to load in that layer. Table 4.3 shows the input and the output of the truck element.

The optimization time of trucks equals the time of loading, traveling (hauling and return), dumping, maneuvering, waiting, and delay. The waiting time of the truck

is either queuing for another truck or waiting for an excavator to be fixed when no

other excavator is able to load.

The speed of the truck can be estimated in two ways: 1) using Caterpillar charts

transformed into a database, or 2) using empirical values derived from historical

data or assumptions. The input list in the pop-up window allows the user to

choose one of the two ways as an "Input Method." When "database" is selected,

the user must upload the database file and specify the truck type. Further details

will be discussed in the next section. In the case of multi-destinations (multiple

sources, placements and/or stockpiles), the destinations can be prioritized.

Table 4.3 The input and the output of the truck element

Input	- Type - ID - Max Speed Input Method (user input or database) - Max Speed when Loaded and Empty (user input selection) (km/hr) (PDF) - Choose Database File Name (database selection) - Average Speed on Site (km/hr) (PDF) - Time Between Breakdowns (hr) (PDF) - Time to Fix (hr) (PDF)	- Heaped Capacity (m^3) - Operating Weight (kg) - Target Gross Machine Weight (kg) - Source, Stockpile and Placement Priorities - Percent of Weight Distribution to Front Tires when Truck is Empty and Loaded (%) - Number of Front and Rear Tires - Distance to Reach Max Speed (m) - Efficiency - Cost Rate ($/hr)

	- Dumping Time (min) (PDF)	- Working Hours per Day (hr)
Overall Output	- General Cost ($/m^3) - Total Maximum, Normal, and Actual Productions (m^3/hr) - Total TKPH (ton-km-per-hr) - Total Bank Volume Hauled (m^3) - Total Travel Distance (empty) (km) - Total Travel Distance (loaded) (km) - Utilization	- Days Worked (round up) (days) - Total Working Time (hr) - Total Travel Time (empty) (hr) - Total Travel Time (loaded) (hr) - Total Loading Time (hr) - Total Dumping Time (hr) - Total Waiting Time (hr) - Total Delay Time (hr)
Cyclic Output	- Loading Excavator - Source Destination - Excavation Area - Placement Destination - Placement Area - Stockpile Destination - Hauled Dirt Type - Payload (ton) - Bank Volume Hauled (m^3) - Loose Volume Hauled (m^3) - Cost ($/m^3) - Maximum, Normal, and Actual Production (m^3/hr) - TKPH (ton-km-per-hr) - Travel Time (empty) (min)	- Travel Time (loaded) (min) - Dumping Time (min) - Loading Time (min) - Waiting Time (min) - Delay Time (min) - Travel Distance (empty) (m) - Travel Distance (loaded) (m) - Empty Weight on Individual Front Tire (ton) - Empty Weight on Individual Rear Tire (ton) - Loaded Weight on Individual Front Tire (ton) - Loaded Weight on Individual Rear Tire (ton)

4.6.3.2 Excavator Element

The excavator element represents equipment used for excavation operations. It is assigned to a dirt layer in the source, and only leaves the layer when no quantities are left to excavate. The excavator cycle begins when the excavator starts loading a truck, and finishes when it is done loading (the truck is at capacity). Table 4.4 shows the input and the output of the excavator element.

The optimization time of the excavator equals the loading time of a truck. Its waiting time accounts for its time spent when no trucks are available for loading, or when the excavator is assigned to an LFH or muskeg layer and it waits on a stripping dozer to collect enough soil quantity to be loaded.

Table 4.4 The input and the output of the excavator element

Input	- Type - ID - Bucket Heaped Capacity (m^3) - Bucket Cycle Time (min) (PDF) - Average Angle of Swing (degree) - Maximum Digging Depth (m) - Time Between Breakdowns (hr) (PDF)	- Time to Fix (hr) (PDF) - Efficiency - Cost Rate ($/hr) - LFH Fill Factor - Muskeg Fill Factor - Secondary Fill Factor - Working Hours per Day (hr)
Overall Output	- General Cost ($/$m^3$) - Total Maximum, Normal, and	- Days Worked (days) - Total Working Time (hr)

	Actual Productions (m³/hr)	- Total Loading Time (hr)
	- Total Bank Volume Excavated (m³)	- Total Waiting Time (hr)
	- Utilization	- Total Delay Time (hr)
	- Average Swing Depth Factor	
Cyclic Output	- Source Destination	- Cost ($/m³)
	- Excavation Area	- Maximum, Normal, and
	- Truck Loaded	Actual Production
	- Excavated Dirt Type	(m³/hr)
	- Bucket Cycle	- Loading Time (min)
	- Bank Volume Hauled (m³)	- Waiting Time (min)
	- Loose Volume Hauled (m³)	- Delay Time (min)

4.6.3.3 Dozer Element

Dozer elements represent equipment used for stripping and spreading operations. The dozer is assigned to either a source or placement unit area, and leaves only when there are no quantities left to strip in the source, or when the required volume is met in the placement. A single dozer is dedicated to one operation only: either stripping or spreading. The user can specify the operation type by selecting "stripping" or "spreading" in the input list. The input and output differ based on the user's choice of the operation type. Table 4.5 shows the input and the output of the dozer element (spreading and stripping).

The optimization time of the dozer equals either its spreading time or its stripping time. The waiting time of the spreading dozer accounts for its time spent waiting for new quantities of dirt available to be loaded (dumped by trucks).

For the spreading dozer, the ideal production can be estimated in two ways: 1) using Caterpillar charts transformed into a database, or 2) using empirical values derived from historical data or assumptions. The input list allows the user to choose one of the two ways by choosing an "Input Method." In case of database, the user shall upload the database file and specify the dozer blade type, then specify the distance of spreading. Further details will be discussed in the following section.

Table 4.5 The input and the output of the dozer element (spreading and stripping)

Stripping Input	- Type - ID - Job Type (stripping or spreading) - Amount to strip Before Requesting an Excavator (m^3) - Time Between Breakdowns (hr) (PDF)	- Blade Capacity (m^3) - Time to Fix (hr) (PDF) - Time to Strip One Meter Square (min) (PDF) - Efficiency - Cost Rate (\$/hr) - Working Hours per Day (hr)
Stripping Overall Output	- General Cost $(\$/m^3)$ - Total Maximum, Normal, and Actual Productions (m^3/hr) - Total Area Stripped (m^2) - Total Bank Volume Stripped	- Utilization - Days Worked (days) - Total Working Time (hr) - Total Stripping Time (hr) - Total Waiting Time (hr)

	(m^3)	- Total Delay Time (hr)
Stripping Cyclic Output	- Excavation Destination - Excavation Area - Cost ($/m^3$) - Maximum, Normal, and Actual Production (m^3/hr) - Area Stripped (m^2) - Stripping Trips	- Average Trip Time (min) - Stripping Time (min) - Waiting Time (min) - Delay Time (min) - Bank Volume Stripped (m^3) - Loose Volume Stripped (m^3)
Spreading Input	- Type - ID - Job Type (stripping or spreading) - Blade Capacity (m^3) - Ideal Production Input Method (user input or database) - Ideal Production (user input selection) (m^3/hr) (PDF) - Blade Type (database selection) - Distance of Spreading (database selection) (m) (PDF) - Time Between Breakdowns (hr) (PDF)	- Time to Fix (hr) (PDF) - Wheel Type (Track or Wheels) - Grade Percent (%) - Material Type - Operator Skill - Visibility - Machine Transmission Factor - Operating Technique - Efficiency - Cost Rate ($/hr) - Working Hours per Day (hr)
Spreading Overall Output	- General Cost ($/m^3$) - Total Maximum, Normal, and Actual Productions (m^3/hr) - Total Bank Volume Spread (m^3) - Utilization - Grade Factor - Material Type Correction Factor - Visibility Technique Correction	- Operator Skill Correction Factor - Operating Technique Correction Factor - Days Worked (days) - Total Working Time (hr) - Total Spreading Time (hr) - Total Waiting Time (hr)

	Factor	- Total Delay Time (hr)
Spreading Cyclic Output	- Placement Destination - Placement Area - Spread Dirt Type - Cost ($/m^3) - Maximum, Normal, and Actual Production (m^3/hr) - Ideal Production (m^3/hr) - Distance of Spreading (m)	- Spreading Trips - Dumping Time (min) - Spreading Time (min) - Waiting Time (min) - Delay Time (min) - Bank Volume Spread (m^3) - Loose Volume Spread (m^3)

4.6.4 Stockpile Element

The stockpile element is the destination for soil when the placement element(s) cannot receive any amount of a specific layer of soil due to the placement sequence, or if the placement element(s) are full. As discussed in Section 2, the stockpile element represents a temporary stockpile. At least either one placement element or stockpile element should be created in the simulation model. The stockpile element can be connected to source elements or intersection elements. Table 4.6 shows the input and the output of the stockpile element.

Table 4.6 The input and the output of the stockpile element

Input	- None	
Output	- Stockpiled Banked Volume of LFH(m^3) - Stockpiled Banked Volume of Muskeg (m^3)	- Stockpiled Loose Volume of LFH(m^3) - Stockpiled Loose Volume of Muskeg (m^3)

	- Stockpiled Banked Volume of Secondary (m^3) - Total Banked Volume Stockpiled (m^3)	- Stockpiled Loose Volume of Secondary (m^3) - Total Loose Volume Stockpiled (m^3)

4.6.5 Road Element

The road element is a virtual element represented as the relationship arrows between elements. In other words, it doesn't exist on the list that contains the template's elements (left of screen). Road elements are used to model a two-way road, and to construct a travel path for the trucks. The road element consists of segments that have different specifications. Each segment could be either straight or curved. Table 4.7 shows the input and the output of the road element.

For estimating travel time, the template allows two methods of calculation: either mathematical or empirical. The mathematical method uses motional physics formulas that deal with acceleration and deceleration, and their relationship with time and distance. The empirical method uses simple equations to estimate travel time, i.e. the distance divided by speed, assuming an average empirical speed, hence, no need to apply motional formulas and involve acceleration.

One note to mention is that it doesn't matter if the truck's speed is taken from direct user input, or via Caterpillar charts transformed into a database, meaning that four (4) scenarios can be used to estimate travel time.

Table 4.7 The input and the output of the road element

Unified Input for all Segments of a Single Road	- Travel Time Calculation Method (mathematical or empirical) - Altitude Factor - Stopping Sight Distance (SSD) (m)	
Segment Input	- Road Type (straight or curved) - Segment Length (m) - Rolling Resistance (RR) (%)	- Grade Resistance (GR) (%) - Maximum Allowable Speed (km/hr) - Superelevation (for curve) - Turn Radius (m) (for curve)
Output	- None	

4.6.6 Intersection Element

The intersection element is a composite element used to connect different elements. It is also used to direct the truck to its destination (by having a branch element as child element), and to model random traffic flow at various locations. It increases the travel time of trucks in the model. The intersection can be either a 4-way or a 3-way intersection. Also, it can have either a stop sign or a traffic light. The intersection element can be connected to source elements, placement elements, stockpile elements, or other intersection elements. The (PDF) abbreviation means that the input is modeled as Probability Distribution Function. Table 4.8 shows the input and the output of the intersection element.

Table 4.8 The input and the output of the intersection element

Input	- Sign Type; Stop Sign or Traffic Light - Incoming Traffic Intervals; East, West, North, South (min) (PDF) - Time for the Truck To Cross (sec) (PDF) - Green Light Duration; East-West, North-South (Traffic Light) (min)
Output	- None

4.6.7 Branch Element

The branch element is used to model multiple paths for the trucks when multiple sources, placements, and stockpiles are used. The branch element can only be created inside the intersection element. By double-clicking on the branch element, the user can set up the directions of the source(s), placement(s), and stockpile(s)

related to the intersection that the branch element belongs to. The directions are set as North, South, West, and East. Table 4.9 shows the input and the output of the branch element.

The branch element will contain a list of all the existing elements in the simulation model, except for resources and intersections. The direction of those elements should be set as the direction of the intersection that connects them, even when some elements are connected to the intersection indirectly (via another intersection). In other words, the user should imagine which direction the truck driver would go to reach the destination. When some elements are not connected to an intersection-branch directly or indirectly, the user shall choose the option "Not Connected." The outlets of the branch should be connected correctly to the outlets of the intersection, i.e. North to North, East to East. So, in a 3-way intersection, the east outlet of the branch should be left disconnected. Figure 4.10 shows a sample of a branch element and direction setup list inside a 3-way intersection.

Table 4.9 The input and the output of the branch element

Input	- Specify directions (North, South, West, East, and Not Connected)
Output	- None
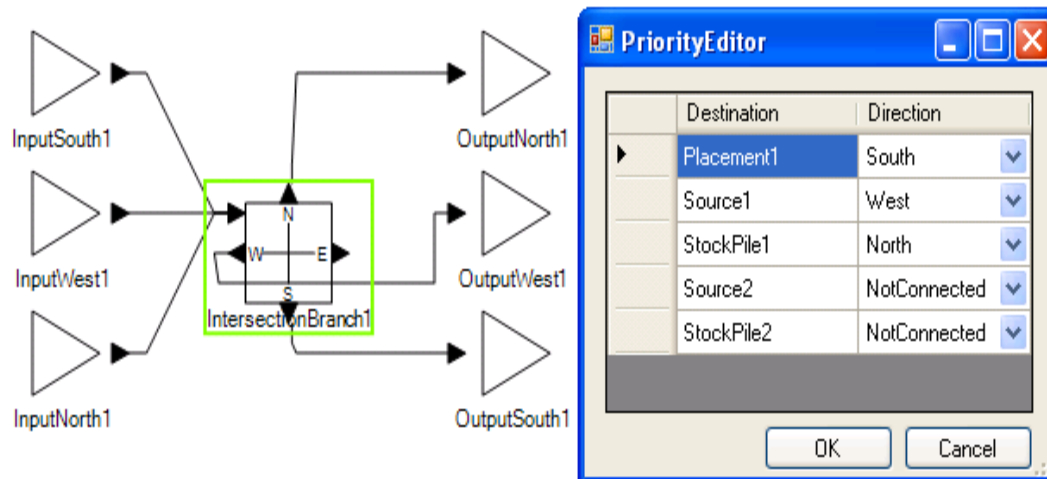
Figure 4.10 The branch element and direction setup list inside a 3-way intersection

4.6.8 Reclamation Element

The reclamation element is where final results are obtained. The final results can be shown as a report. The user can see the description of each output by clicking on an output item. The description is shown at the bottom of the output list on the right of the screen. Table 4.10 shows the input and the output of the reclamation element.

Table 4.10 The input and the output of the reclamation element

Input	- None	
Output LFH Layer	- LFH Actual Reclamation (%) - LFH Required Reclamation (%) - Total Actual Placement(s) LFH Volume (m^3)	- Total Required Placement(s) LFH Volume (m^3) - Total Source(s) LFH Volume (m^3)

Output Muskeg Layer	- Muskeg Actual Reclamation (%) - Muskeg Required Reclamation (%) - Total Actual Placement(s) Muskeg Volume (m^3)	- Total Required Placement(s) Muskeg Volume (m^3) - Total Source(s) Muskeg Volume (m^3)
Output Secondary Layer	- Secondary Actual Reclamation (%) - Secondary Required Reclamation (%) - Total Actual Placement(s) Secondary Volume (m^3)	- Total Required Placement(s) Secondary Volume (m^3) - Total Source(s) Secondary Volume (m^3)
Output Excavator	- Total Excavator Cost ($) - Total Excavator Time (hr)	- Excavators Actual Production (m^3/hr)
Output Trucks	- Total Trucks Cost ($) - Total Trucks Time (hr)	- Trucks Actual Production (m^3/hr)
Output Dozers	- Total Dozers Cost ($) - Total Dozers Time (hr)	- Dozers Actual Production (m^3/hr)
Output Overall	- Approximate Overall Actual Production (m^3/hr) - Total Cost ($) - Project Duration (hr) - Project Equipment Total Working Time (hr) - Total Actual Reclamation (%)	- Total Required Reclamation (%) - Total Actual Placement(s) Volume (m^3) - Total Required Placement(s) Volume (m^3) - Total Source(s) Volume (m^3)

4.7 SCENARIOS FOR MODELING LAYOUT

4.7.1 Scenarios for Excavation Areas

A) Based on excavation locations:

1) All of the excavation areas are modeled as one unit: one unit area within one source element.

2) All of the excavation areas are modeled as one unit: many area units; each unit represents a polygon with adjustments to the depth to have an equivalent total volume within one source element.

3) If the excavation areas are divided into smaller blocks, then each excavation block is modeled as an excavation unit: one unit area within multi source elements.

4) If the excavation areas are divided into smaller blocks, then each excavation block is modeled as an excavation unit: many area units; each unit represents the excavating locations with adjustments to the depth to have an equivalent total volume within multi source elements.

B) The first scenario has the lowest level of detail and precision among the four scenarios, while the fourth scenario has the highest level. The rest lie in between. Based on soil profile:

1) All soil layer areas are modeled as one excavation unit within one source element.

2) Each soil layer is modeled as one excavation unit within multi source elements.

The first scenario has the lowest level of detail and precision among the two scenarios, while the second scenario has the highest level.

C) A model that mixes scenarios A and B.

4.7.2 Scenarios for Placement Locations

A) Based on placement locations:

1) All of the placement areas are modeled as one unit: one unit area within one placement element.

2) All of the placement areas are modeled as one unit: many area units; each unit represents a polygon with adjustments to the depth to have an equivalent total volume within one placement element.

3) If the excavation areas are divided into smaller blocks, then each excavation block is modeled as an excavation unit: one unit area within multi placement elements.

4) If the excavation areas are divided into smaller blocks, then each excavation block is modeled as an excavation unit: many area units; each unit represents the placement locations with adjustments to the depth to have an equivalent total volume within multi placement elements.

The first scenario has the lowest level of detail and precision among the four scenarios, while the fourth scenario has the highest level. The rest lie in between.

B) Based on soil profile:

1) All soil layer areas are modeled as one placement unit within one placement element.

2) Each soil layer is modeled as one placement unit within multi placement elements.

The first scenario has the lowest level of detail and precision among the two scenarios, while the second scenario has the highest level.

C) A model that mixes scenarios A and B.

4.8 TRANSFORMATION OF CATERPILLAR CHARTS INTO DATABASE TEMPLATES

Transforming charts into databases requires input of point coordinates (X, Y) of curves into an MS Access file. The interval between points X and Y affects the precision of the output values. In other words, the shorter the interval, the more points are taken, which means more precise output values. The user has to balance

time and effort against the desired precision in output values. Computer software for extracting points from charts, such as Data Thief, FindGraph, UN-SCAN-IT and many others, can increase precision and save time. The added costs to purchase software licensing are usually not substantial.

The reclamation template is designed around a specific database structure. Any defect in the structure will prevent the template from getting data. The structure of the database differs depending on the usage: the truck speed's database structure is different than the ideal dozer production's database structure. The various database structures are described in this section.

4.8.1 Truck Speed Charts

4.8.1.1 Database Structure

A database represents a truck type. The tables in the database represent the total resistance values (TR) of the road. Each table contains two main columns: Maximum Speed and Gross Truck Weight. For example, to create a database for a 777F truck:

- Create an MS Access file called "777F."

- Name the tables based on the total resistance values (e.g.: 1% - 30%). The values must be integers, and have the percentage symbol (%) with no spaces.

- Create two columns. The title of the first column MUST be "Weight" and the second column MUST be titled "Speed."

Figure 4.11 shows an example of Truck Speed Database file structure.

Figure 4.11 Database file for 777F truck, the table titles, and the column titles

4.8.1.2 Building the Database File

To populate the rows of each table based on the total resistance that the database table's title holds (30%, 29%, etc.), the user has to:

- Fill the first row with the weight and the corresponding speed of the truck when it is fully loaded.

- Fill the last row with weight and the corresponding speed of the truck when it is empty.

- Fill the rows in between with the weight and the corresponding speed of the truck when it is partially full.

4.8.1.3 Uploading the Database File

To upload the database file:

- Click on the button of the "Databases" input item, in the list on the right side of the model screen.

- Click the "Add" button at the bottom of the uploading screen.

- Find the location of the database file and upload it.

- Name the truck type.

- Click "OK."

Afterwards, the truck type will appear as an item in a list of the truck elements when the user chooses "Database" as the input method. The database file must be uploaded as the right truck type; if not, the template will deal with the file normally, but the values obtained from the file will be wrong, since it is the false truck type.

Note that if the simulated truck weight value doesn't match any value in the database file, the closest weight value will be chosen, then obtaining the corresponding speed value.

Figure 4.12 shows the uploading screen for the truck's database file.
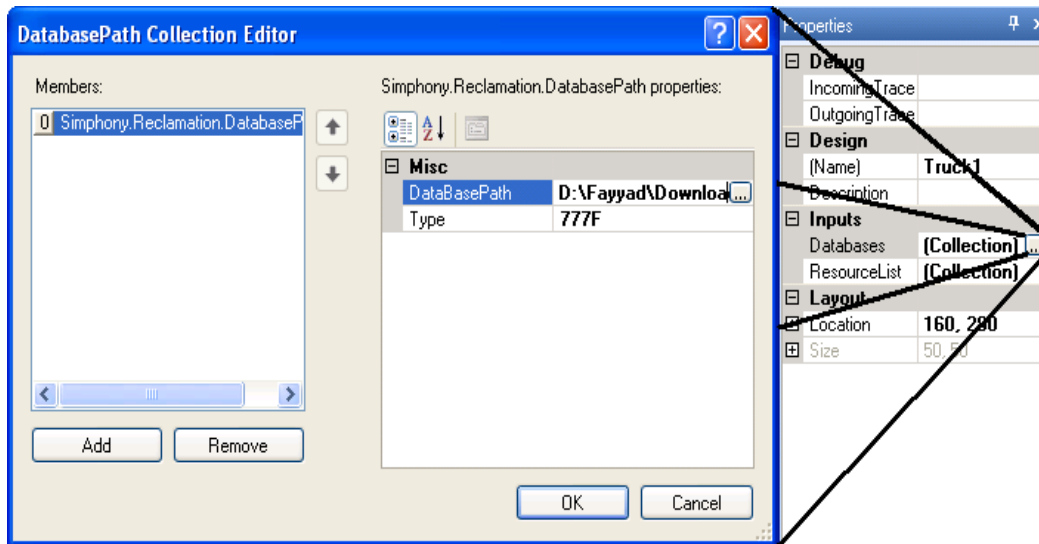
Figure 4.12 The uploading screen for truck's database file

4.8.2 Dozer Ideal Production Charts

4.8.2.1 Database Structure

A database file represents a dozer's blade type. The tables in the database file represent the dozer types. Each table contains two main columns: "Distance of Spreading" and "Dozer's Ideal Production." For example, for a Semi-Universal blade:

- Create an MS Access file called "Semi-Universal Blade."

- Name the tables based on the dozer type (e.g. D6T, D8T, etc.).

- Create two columns: the title of the first column MUST be "Distance of Spreading" and the title of the second column MUST be "Ideal Production."

Figure 4.13 shows an example of Dozer Ideal Production Database file structure.

Figure 4.13 Database file for semi-universal blade, the table titles, and the column titles

4.8.2.2 Building the Database File

To fill the rows of each table, the user has to fill the rows with the distance of spreading and the corresponding ideal production values.

4.8.2.3 Uploading the Database File

To upload the database file:

- Click on the button of the "Databases" input item, in the list on the right side of the model screen.

- Click the "Add" button at the bottom of the uploading screen.

- Find the location of the database file and upload it.

- Name the blade type.

- Clicking the "OK" button.

The truck type will appear as an item in the dozer element list when the user chooses "Database" as the input method. The dozer type MUST be written

identically in one of the table titles in the corresponding database file. Otherwise, the template will fail to obtain the required value.

Note that if the simulated distance of spreading value doesn't match any value in the database file, the closest value for distance of spreading will be chosen, then obtaining the corresponding ideal production value. Figure 4.14 shows the uploading screen for the dozer's database file.
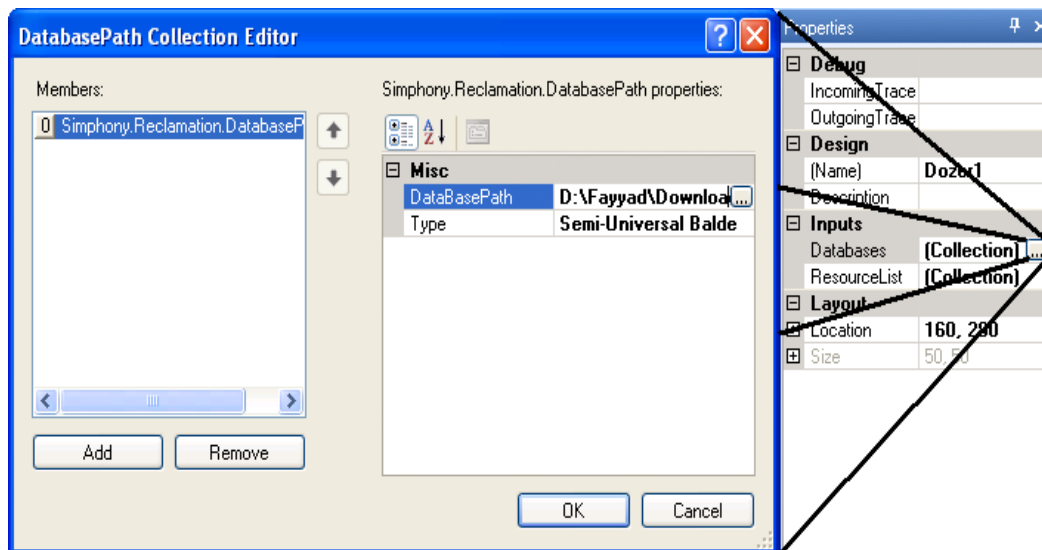
Figure 4.14 The uploading screen for dozer's database file

4.9 CONVERTING THE RECLAMATION TEMPLATE INTO AN EARTHMOVING TEMPLATE

The reclamation template is flexible, and can be converted to model earthmoving operations. The following procedure has to be done totally or partially, depending on the case:

- The soil profile layer specifications can be manipulated easily, regardless of the soil layer's name (LFH, muskeg and secondary). In other words, the LFH layer would have rock specifications if the user sets the density, swell factor and the excavator's fill factor. However, it would still have the LFH name.

- For the sequence of dirt placement, the soil profile layers can be controlled by setting the placed depth of the unwanted layers at zero, so that these layers can be skipped and won't be placed. This functionality offers placing a 1-3 layer combination within a single unit area, e.g. 1 layer, muskeg only; 2 layers LFH and secondary; or 3 layers, LFH, muskeg and secondary. The application of the first point (rock specifications instead of LFH), can also be included in this configuration.

- The excavator element mainly represents hoes, but it can be converted to represent front shovels, since they share the same general specifications. The slight difference between the two is the swing-depth (height) factor. This factor affects the production rate estimation, but can be avoided by predicting the swing-height factor of the shovel on site and making adjustments to the swing-depth factor of the excavator unit in the excavator element.

- The stripping operation can be eliminated by disengaging the stripping dozers. This can be done by setting the "Time to strip one meter square" and "Amount to Dozer before Requesting an Excavator" in the stripping dozers' input list to zero.

CHAPTER 5 CASE STUDY

5.1 INTRODUCTION

This chapter presents a case study to clarify the implementation methodology of the reclamation template using historical data from a practical existing project. Actual results of the project such as duration, equipment production, cost, and dirt quantities reclaimed will be compared with project results obtained from simulation. This is necessary to test the practicality and to validate the applicability of the reclamation template in planning for reclamation projects. In addition to practicality validation, the reclamation template will be validated through the general purpose template of Simphony.NET to ensure that the simulation behavior and algorithm performed according to the anticipated design requirements. This validation will take place by constructing two models with the same input — the first model using the reclamation template and second model using the general purpose template — then comparing the results of both models to check the validity of the reclamation template.

5.2 PROJECT DESCRIPTION

The case study considers the first year of the reclamation phase of the mining services project for Syncrude Leases in Mildred Lake Oil Sands, Aurora North Oil Sands and Aurora South Oil Sands; all are approximately 40 km north of Fort

McMurray, Alberta, Canada. The total dirt bank volume of the project site is about 7,700,000 m^3 in total; consisting of 370,000 m^3 of LFH, 2,030,000 m^3 of muskeg, and 5,300,000 m^3 of secondary.

In the first year of the project, the salvaged dirt will be dumped in a temporary stockpiling area. Then that dirt will be transported and replaced in the area that needs to be reclaimed. The salvaging process contains topsoil (LFH and muskeg) salvage, and subsoil (secondary) salvage. The LFH depth ranges from 0.15 m to 0.3 m, the muskeg depth ranges from 0.3 m to 3 m, and the secondary depth ranges from 0.5 m to 3 m.

The LFH material is salvaged and windrowed into piles during the late summer and early fall timeframe to avoid snowfall and rainfall. Then the LFH material will be loaded and hauled to stockpile or directly to placement location during winter time. The muskeg and secondary subsoil materials are salvaged in winter to avoid the high water table's effect, and to freeze the working areas so they are more stable to support large equipment. The LFH, the muskeg and secondary material are loaded and hauled to stockpile or directly to placement location during winter time; however, the material will be re-spread in summer after thawing to achieve the required reclamation standards, since it is hard to accomplish when the material is frozen. The dirt material will be placed for reclamation work in Aurora and Mildred Lake.

5.3 PROJECT LAYOUT

The excavation (salvage) locations and placement/stockpiling locations are classified according to the type of the dirt material. For LFH, there are two salvage locations accompanied with two stockpile locations. The first salvage location is W4 Reclamation-Stockpile. The LFH salvage is placed within the same location (W4 Reclamation-Stockpile), hence, the average hauling route distance is 1 km. The second location is Cell31. The LFH salvage is placed within the same location (Cell31), hence, the average hauling route distance is 800 m.

There are three salvage locations for muskeg and secondary salvage with one placement location. The salvage locations are North Mine Wall (NMW), W4 Road, and W4 Dump. The muskeg and secondary salvage from these locations is placed in the W4 Reclamation Stockpile only. The average haul distances from North Mine Wall (NMW), W4 Road, and W4 Dump to W4 Reclamation-Stockpile are 8 km, 6 km, and 4 km, respectively. Figure 5.1 shows an aerial view of the layout of the salvage and placement locations.
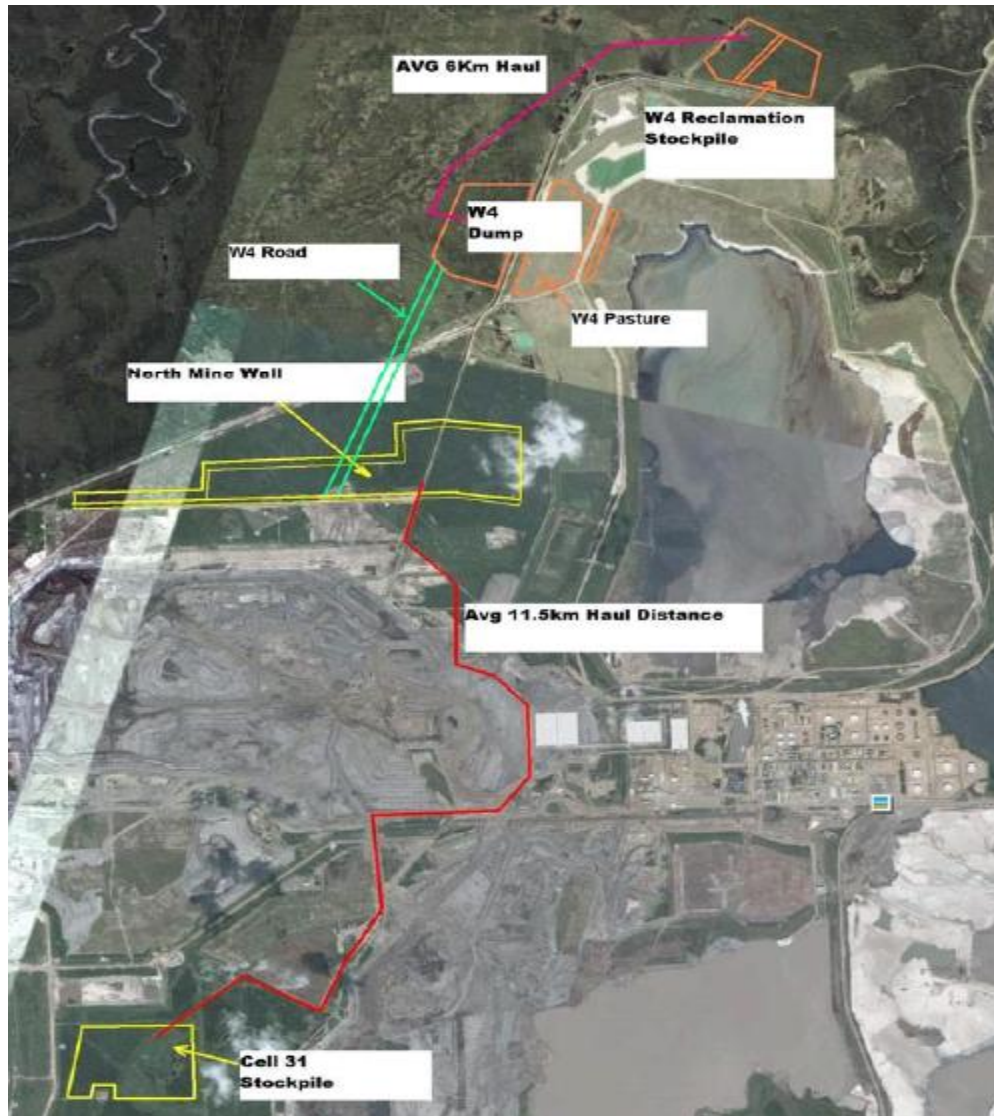
Figure 5.1 Aerial view of the layout of the salvage and placement locations

The muskeg and secondary salvage locations are divided into area polygons. Each polygon is treated as a separate unit of control, with specific working equipment, working dates, and haul route distance. Figure 5.2 shows the polygons of the topsoil (muskeg) salvage locations, and Figure 5.3 shows the polygons of the subsoil (secondary) salvage locations.
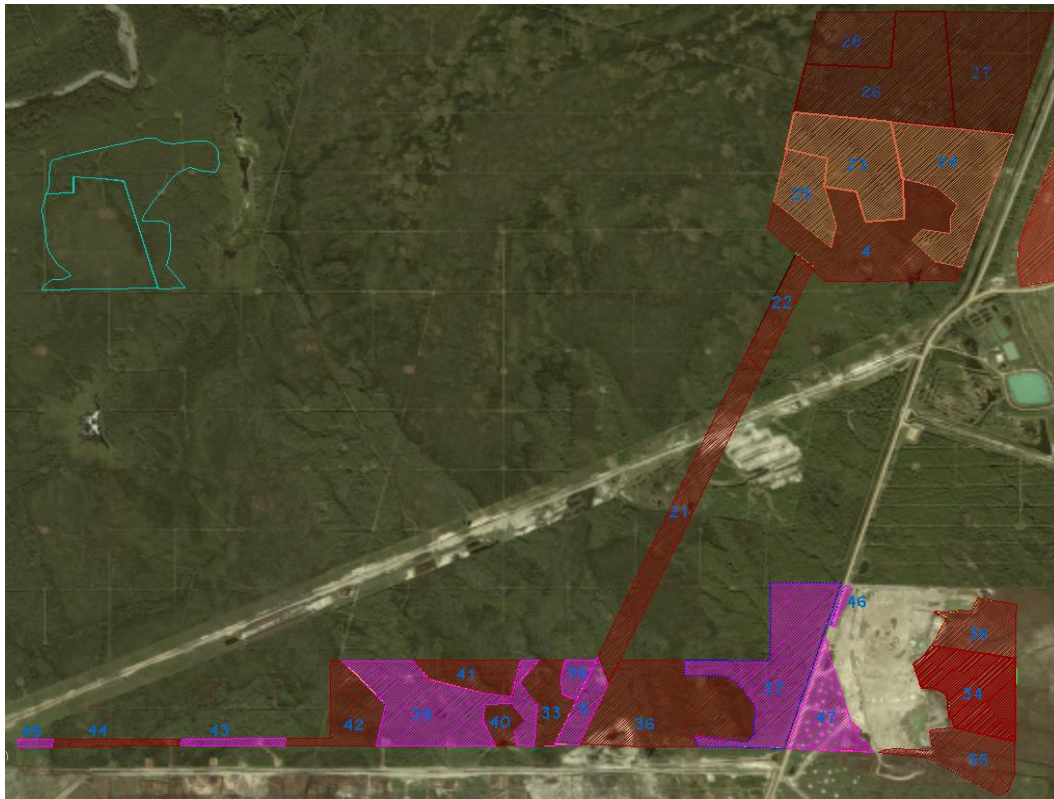
Figure 5.2 Polygons of the topsoil (muskeg) salvage locations
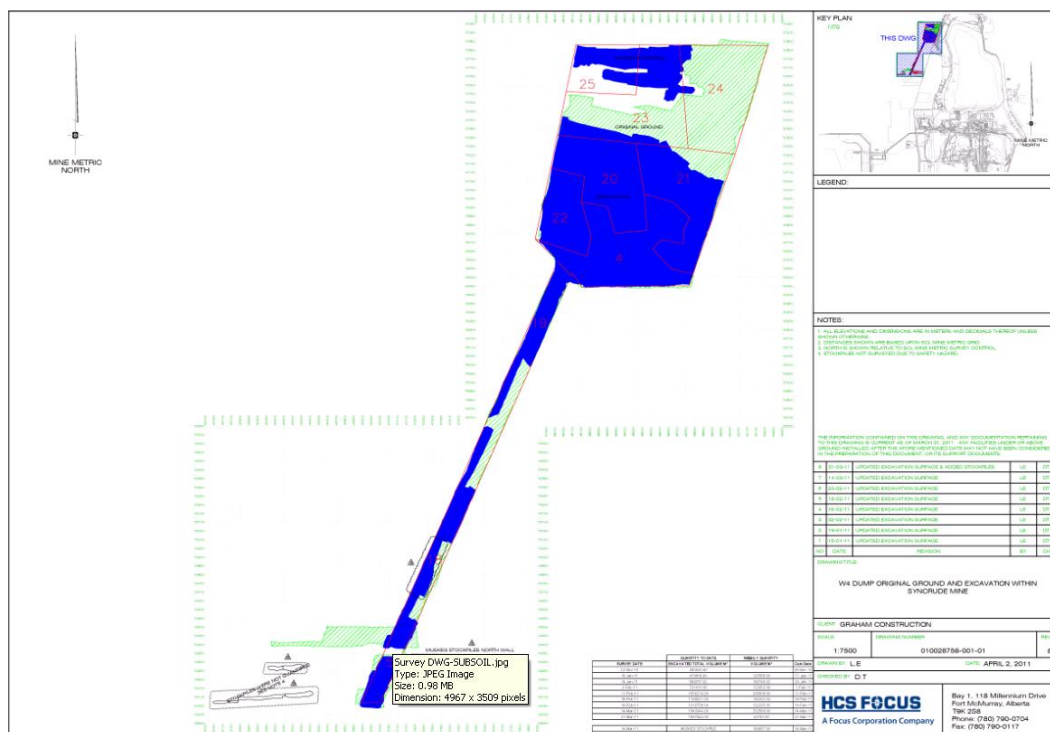
Figure 5.3 Polygons of the subsoil (secondary) salvage locations

5.4 EQUIPMENT CRITERIA AND SELECTION

The diversity of the activities and the intensive work of the project require various equipment types and different criteria. In this project, excavators, trucks and dozers are the main equipment involved in the project, in addition to some other equipment such as graders, scrapers, snow cats and challengers. Table 5.1 shows equipment types and numbers that are involved in the project.

Table 5.1 Equipment types and numbers that are involved in the project

Equipment	Model	Quantity
Excavators	EX2500	1
	EX1900	2
	EX1200	2
	EX850	2
Trucks	793	8
	789	8
	785	14
	777	28
Dozers	D11	1
	D10	5
	D9	4
	D8	3
	D6	2
Graders	24M	1
	16M	2
Scrapers	631	2

Graders are used for snow clearing throughout the winter season as well as haul road maintenance. The scrapers are used for sanding.

Excavators are usually assigned based on the dirt material type. For LFH material salvage, small-sized excavators like Ex850 and sometimes medium-sized excavators like Ex1200 are used. The muskeg material is salvaged by medium-sized excavators like Ex1200 and Ex1900. Finally, the secondary material is salvaged by medium-sized excavators like Ex1900 and heavy-sized excavators like Ex2500.

Similarly, trucks are usually assigned based on the dirt material type. For hauling the LFH material, small-sized trucks like 777F are used. The muskeg material is hauled by small-sized trucks like 777F and medium-sized trucks 785D and 789C. Finally, the secondary material is hauled by medium-sized trucks like 785D and 789C, and heavy-sized trucks like 793D.

Dozers are used mainly for spreading the dumped dirt salvage material in the placement and stockpile locations. In addition, they are used for stripping the topsoil material (LFH and muskeg) and assisting the excavators in the loading process. Dozer types DT6 and DT8 are used for spreading activities, and dozer types DT9 and DT10 are used for stripping activities and assisting excavators.

5.5 SIMULATION MODEL

The case study covers the period of the first 10 days of December, 2010. Within these 10 days, the LFH material salvage (excavation) location is the W4 Reclamation Stockpile, and muskeg and secondary material salvage (excavation) location is the W4 Dump. The muskeg material salvage polygons of W4 Dump that are included in the case study are: Polygon 4, Polygon 23, Polygon 24, Polygon 25, and Polygon 27. The secondary material salvage polygons of W4 Dump that are included in the case study are: Polygon S21 and Polygon S24. The length of the hauling route is about 5 km in average between the W4 Dump location and the W4 Reclamation Stockpile location.

The LFH material exists in W4 Reclamation Stockpile, which makes the length of the hauling route about 0.5 km. Hence, the LFH material is excluded from the case study for the sake of harmonizing the model; to take the LFH material into consideration, the case study has to cover a large amount of time, from approximately 1 month to the scope of the whole project. In addition, Polygon 21, which holds muskeg material quantities, lies on the W4 Road section and has earthwork operations only during the night shift of the 10th of December (the last day covered by the case study). Also, the length of the hauling route between Polygon 21 and W4 Reclamation Stockpile is about 8 km. So, Polygon 21 was omitted in the case study because it holds a very little amount of muskeg compared to other polygons, and it needs to be treated as an independent dirt source during this time due to the length of the haul route.

5.5.1 Model Layout

The case study can be modeled in different ways (scenarios). The best scenario can be chosen by breaking down the model elements.

Starting with the placement location, there is only one placement location in the project with three spreading areas, in which each spreading area represents a dirt material type (LFH, muskeg, and secondary).

The source element is the actual challenge for modeling, as many scenarios can be presented; one scenario encapsulates the whole excavation areas to one source element consisting of one unit area. The hauling route's length represents the distance between the centroid of the overall excavation area and the centroid of the placement area.

A second scenario is to have several source elements in which each one represents a polygon; each source element consists of one unit area. The hauling route length of each source element represents the distance between the centroid of the polygon and the centroid of the placement area.

A third scenario would be to have one source element that consists of several unit areas, in which each unit area represents a polygon. The hauling route's length represents the distance between the centroid of the closest polygon to the placement area and the centroid of the placement area.

A fourth possible scenario would be to have several source elements that consist of several unit areas, in which each source element represents a polygon. The hauling route's length represents the distance between the centroid of the closest excavation unit area within the polygon to the placement area and the centroid of the placement area.

The first scenario is very simple and rough and does not come up with adequate results for an advanced phase, but works well for preliminary design periods. The second scenario is also somewhat simple and good for preliminary phases, but it is also useful when the excavation areas are scattered and disconnected, hence, it is important to model the hauling route for each excavation area separately. The third scenario is more complicated, but it is appropriate to use when there is not enough information about the excavation places within the polygons, especially equipment allocation data. Finally, the fourth scenario is more complicated and detailed than the third scenario, so it can be used in more advanced planning stages or project control, but it is similar to the second scenario in that it is useful when the excavation areas are scattered and disconnected.

The scenario adopted in the case study to model the 10 days of reclamation earthworks is the third scenario. This scenario has one source element that consists of several unit areas; each unit area represents a polygon. The first reason for choosing this scenario is that the polygons are connected and adjacent to one

other, so it is important to model the site conditions rather than manipulating the route haul conditions to act like the working site. The second reason is that there is only one hauling route between W4 Dump (source) and W4 Reclamation Stockpile (placement); hence, it is better to make a model with one source element to reflect reality. The third reason is that there are no sufficient details about truck allocation within the same polygons; the information available about truck allocation is based on days, not on location within a polygon.

Because of the ability to model the equipment pieces of each type as lists, only one element of each equipment type is needed (truck, excavator, and dozer). One intersection element is needed to connect the source element with the placement element and to model traffic. One reclamation element is needed for visualizing the final overall results and reporting. Finally, there is no need for stockpile element since all of the dirt material will be placed and spread, and each dirt type (LFH, muskeg, and secondary) is spread separately and not above one another, so this dirt material would be used in the future to reclaim the land/mine.

From the previous discussion, it was concluded that the best model should consist of the following: one source element with several unit areas, one placement element with three unit areas, one truck element, one excavator element, one dozer element, one intersection element and one reclamation element. Figure 5.4 shows the case study model layout in Simphony.NET 4.0.
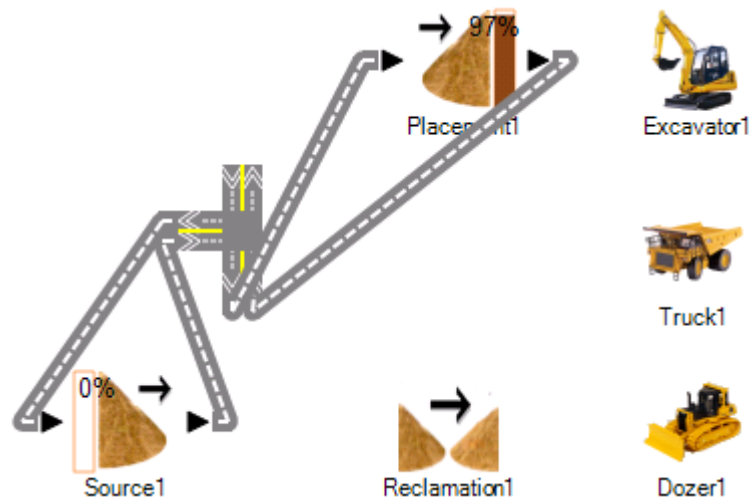
Figure 5.4 The case study model layout in Simphony.NET 4.0

5.5.2 Model Input

5.5.2.1 Source Element

The source element represents the W4 Dump site with 7 unit areas representing Polygons 4, 23, 24, 25, 27, S21, and S24. Table 5.2 shows the general input of the source element.

Table 5.2 General input of the source element

Unit Areas to be Excavated	7
Dimensions of Unit Area (m^2)	500 X 100
Site Condition	Favourable
Entry and Exit Area	Top Left Corner
LFH Swell Factor	0.11
Muskeg Swell Factor	0.05
Secondary Swell Factor	0.25
LFH Bank Density (kg/m^3)	800
Muskeg Bank Density (kg/m^3)	1300
Secondary Bank Density (kg/m^3)	2080

The soil layer specifications (swell factor and density) were provided by Syncrude (2010), and the site condition was assumed to be favourable. Given the dirt volumes and layer depths of each polygon, and assuming that each polygon has a square shape, it was found that the side dimension of the polygons ranges between 50 m and 500 m. Since the unit area dimensions must be unified, this indicates that the unit area's dimensions should fall within the aforementioned range.

Also, it is better to suggest unified dimensions that make it easy to model the locations of the polygons in a way that preserves the distances between the polygons and the placement. The average distances, approximated to the closest 50 m, between Polygons 4, 23, 24, 25, 27, S21, and S24, and the placement are 5450 m, 5150 m, 5250 m, 5300 m, 3750 m, 4300 m, and 4200 m, respectively. As a result of studying the previous information, the distance between the source element and placement element should be 3650 m with an entrance on the top left of the source element's 2D grid layout; the source element's size is better to have 4 X 4 unit areas, and the best dimension candidate is 500 X 100 m^2, which offers 500 and 100 incremental increases to the distance from the entrance. For example, Polygon 27 is 3750 m away from the placement; however Polygon 23 is 5250 m away. So, if the entrance of the source element is 3750 m away, the truck needs to travel one unit area south or north of the entrance to reach Polygon 27 (100 m increment), and it needs to travel west or east to reach Polygon 23 (500 m increment). Figure 5.5 illustrates the layout of the unit areas (polygons) inside the source element.

Figure 5.5 The layout of the unit areas (polygons) inside the source element

Since the dirt volumes of the polygons are known, the soil layer depths can be adjusted by dividing the volumes by the unit area of the source element. Table 5.3 shows the input details of the source element's unit areas (polygons).

Table 5.3 Input details of source element's unit areas (polygons)

Polygon	Distance from the Placement (m)	Volume (m^3)	Adjusted Muskeg Depth (m)	Adjusted Secondary Depth (m)	Priority (Sequence)
Polygon 4	5450	92742	1.855	-	3
Polygon 23	5150	72152	1.433	-	6
Polygon 24	5250	71427	1.429	-	4
Polygon 25	5250	29290	0.586	-	5
Polygon 27	3750	16414	0.328	-	7
Polygon S21	4300	11145	-	0.223	1
Polygon S24	4200	5440	-	0.109	2

The priority sequence of the polygons was arranged according to the actual sequence of the excavation operations in the project, keeping in mind that priority sequence could have some exceptions depending on the availability of the allocated excavator(s).

Finally, the allocation of the equipment unit (excavators, trucks, and stripping dozers) for each polygon is illustrated extensively in Appendix (A).

5.5.2.2 Placement Element

The source element represents the W4 Reclamation-Stockpile site with 2 unit areas representing muskeg material placement and secondary material placement. Table 5.4 shows the general input of the placement element.

Table 5.4 General input of the placement element

Unit Areas for Placement	2
Dimensions of Unit Area	500 X 500
Site Condition	Favourable
Entry and Exit Area	Top Left Corner

Since there are no specific requirements for the depth of the placed dirt layers, the area of the placement locations are unknown, and since the unit area dimensions must be unified, it is better to suggest a unified dimensions layout that reflects realistic soil layer depths and doesn't make any difference in the hauling distance according to the hauled dirt type. As a result of studying the previous information, with an entrance on the top left of the source element's 2D grid layout, it is better to have 2 X 2 unit areas for the placement element's size, and the best candidate is a square with dimensions of 500 m; this offers a 500 incremental increase to the distance from the entrance whether it is north-south or east-west. In other words,

the truck will travel 500 m to reach the muskeg placement area, or to reach the secondary placement area. Figure 5.6 illustrates the layout of the unit areas inside the placement element.
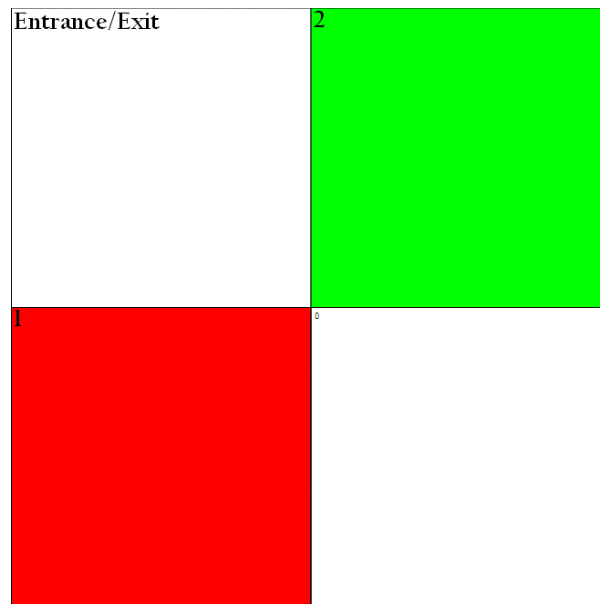
Figure 5.6 The layout of the unit areas inside the placement element

The soil layer depths can be adjusted by dividing the required placed volumes by the unit area of the placement element. The site condition was assumed to be favourable. Table 5.5 shows the input details of the placement element's unit areas.

Table 5.5 Input details of placement element's unit areas

Unit Area	Muskeg Depth (m)	Secondary Depth (m)	Existing Layer Originally	Priority (Sequence)
Muskeg Dump	1.13	-	Muskeg	1
Secondary Dump	-	0.07	Overburden	2

The priority sequence of the unit area is not important since only one dirt type will be dumped in a unit area. In other words, the truck holding muskeg material will dump it in the muskeg dump unit area (Area 1) and the one holding secondary material will dump it in the secondary dump unit area (Area 2). The layer that existed originally before placement was assumed to constrain the unit areas to receive one type of dirt.

Finally, all of the existing spreading dozers are assigned for the two polygons. A polygon will call any available spreading dozer to spread the dumped material.

5.5.2.3 Excavator Element

The excavator element represents three types of Hitachi excavators used in the case study: Ex850, Ex1200, and Ex1900. Type Ex850 has three excavator units, distinguished by IDs given to them; the three unit IDs are: 41-154, 41-15002, and 41-15006. Type Ex1200 has two excavator units: 41-1601 and 41-1602. Type Ex1900 has one excavator unit: 41-1702. Table 5.6 shows the input of the excavator units.

Table 5.6 Input of the excavator units

Input	Ex850	Ex1200	Ex1900
Number of Excavators	3	2	1
Bucket Heaped Capacity (m^3)	3.9	6.7	12
Bucket Cycle Time (min)	0.25	0.45	0.55
Maximum Digging Depth (m)	9.57	9.26	9.23
Average Angle of Swing (degrees)	45	45	45
Efficiency	0.9	0.9	0.9
Cost Rate ($/hr)	-	-	-
LFH Fill Factor	1	1	1
Muskeg Fill Factor	0.9	0.9	0.9
Secondary Fill Factor	0.95	0.95	0.95
Working Hours per Day (hr)	13.5	13.5	13.5
Time Between Breakdowns (hr)	1000	1000	1000
Time to Fix (hr)	20	20	20

Due to the insufficient information on efficiency, angle of swing, and fill factors, their values were assumed according to the most common values. During the working days that the case study covers, no breakdown incidents were recorded, so it is better to choose a high number for the breakdown values, so that no breakdowns occur during the simulation.

In this project, the daily work was distributed into two shifts: day shift and night shift. Combining both shifts' working time ranges between approximately 9 hours and 18 hours so the average is 13.5 hours. Also, typically, the day shift is 9 hours (8 working hours plus lunch break), and the night shift is half the day shift period, which means 13.5 hours in total. As a result, working hours per day was assumed to be 13.5 hours.

Due to record confidentiality with the contracting company Graham, and since there is no actual data to compare the simulation results with, the cost rate was not involved. The rest of the input is machine standards taken from the manufacturer (Hitachi, 2011).

Excavator allocation was performed by assigning units to the polygons. Table 5.7 shows the excavators allocation for source polygons.

Table 5.7 The excavator allocation for source polygons

Ex850		Ex1200		Ex1900	
Excavator ID	No. of Polygons	Excavator ID	No. of Polygons	Excavator ID	No. of Polygons
41-154	5	41-1601	3	41-1702	5
41-15002	4	41-1602	5		
41-15006	2				

5.5.2.4 Truck Element

The truck element represents three types of Caterpillar trucks used in the case study. These types are 777F, 785D, and 793D. Type 777F has sixteen truck units, distinguished by IDs given to them; the sixteen unit IDs are: 44-2411, 44-2412, 44-2413, 44-2414, 44-2415, 44-2416, 44-2417, 44-2418, 44-2419, 44-2420, 44-2421, 44-2422, 44-2423, 44-2424, 44-248, and 44-249. Type 785D has seven truck units: 44-2511, 44-2512, 44-2513, 44-2514, 44-2515, 44-2516, and 44-259. Type 793D has four units: 44-273, 44-276, 44-277, and 44-278. Table 5.8 shows the input of the truck units.

Table 5.8 Input of the truck units

Input	777F	785D	793D
Number of Trucks	16	7	4
Heaped Capacity (m^3)	60.2	78	176
Target Gross Machine Weight (kg)	163293	249476	383673
Dumping Time (min)	0.5	1	1.5
Source, Stockpile and Placement Priorities	-	-	-
Percent of Weight on Front Tires When Empty	0.45	0.46	0.47
Percent of Weight on Front Tires When Loaded	0.33	0.33	0.33
Distance to Reach Max Speed (m)	1000	1000	1000
Number of Front Tires	2	2	2
Number of Rear Tires	4	2	2
Efficiency	0.9	0.9	0.9
Cost Rate ($/hr)	-	-	-
Working Hours per Day (hr)	13.5	13.5	13.5
Time Between Breakdowns (hr)	1000	1000	1000
Time to Fix (hr)	20	20	20

Dumping time was taken from the spreadsheet of the original plan of the project. Due to the insufficient information about efficiency and the distance to reach max speed, they were assumed according to the most common values.

No breakdown incidents were recorded during the working days that the case study covers, so it is better to choose a high number for breakdowns so that no breakdowns occur during the simulation.

The total working hours per day were assumed to be 13.5 hours (as discussed in the excavator element section). Again, due to the records confidentiality with the contracting company Graham, and since there is no actual data to compare the

simulation results with, the cost rate was not involved. The rest of the input, other than the speeds, is machine standards taken from the manufacturer (Caterpillar, 2010).

There are two input methods for the maximum speeds:

1) Manufacturer values taken from Caterpillar Performance Handbook (2010). These were based on total resistance of 3%; however, no database was used. Hence, there are only two speeds for each truck type: when it is empty, and when it is loaded, in which the partially loaded truck is considered fully loaded. The reason for this is that the occurrences of partially loaded trucks are minimal compared to fully loaded occurrences, and the impact of that speed change will not significantly impact the values for the overall duration of the project. For the speed on site, the truck path's condition on site is always changing due to continuous excavation and grading, so it was concluded that the average speed on site would be 35 km/hr. This comes from the average between 60 km/hr speed resulting from an empty truck traveling on good condition ground, and 10 km/hr speed resulting from a loaded truck traveling on good condition ground.

2) Average values resulting from historical data are taken from the trucks Vital Information Management system (VIMs), in which the data was collected from the same project within the duration covered by the case study. Unlike

the previous method in which speed values are assigned according to the truck type, the speed values of this method are assigned according to truck units. For the speed on site, the VIMs speed values take the speed on site into consideration, thus, the speed on site input value is the average of the two VIMs speed values, when the truck is empty and when it is fully loaded.

Table 5.9 shows the truck speed input methods along with speed values used in the case study.

Table 5.9 Truck speed input methods and speed values used

Truck ID	VIMs			Truck Type	Caterpillar charts		
	Speed When Loaded	Speed When Empty	Speed on Site		Speed When Loaded	Speed When Empty	Speed on Site
44-2411	27.13	27.93	27.53	777F	60.00	43.00	35.00
44-2412	27.61	28.69	28.15				
44-2413	27.25	29.79	28.52				
44-2414	29.07	29.29	29.18				
44-2415	15.43	18.30	16.87				
44-2416	22.59	25.31	23.95				
44-2417	25.07	25.42	25.24				
44-2418	29.41	28.68	29.04				
44-2419	25.73	26.54	26.13				
44-2420	28.85	29.17	29.01				
44-2421	24.06	23.70	23.88				
44-2422	28.97	29.20	29.08				
44-2423	15.38	17.80	16.59				
44-2424	25.84	23.38	24.61				
44-248	25.60	25.25	25.42				
44-249	28.70	27.42	28.06				
44-2511	28.44	28.43	28.44	785D	55.00	42.00	35.00
44-2512	18.99	21.11	20.05				

44-2513	26.72	27.84	27.28				
44-2514	23.93	23.77	23.85				
44-2515	21.43	22.85	22.14				
44-2516	19.93	19.49	19.71				
44-259	29.41	29.56	29.48				
44-271	25.17	26.25	25.71				
44-272	26.05	28.69	27.37				
44-273	20.66	28.18	24.42				
44-274	27.40	28.62	28.01	793D	58.00	49.00	35.00
44-275	21.92	23.90	22.91				
44-276	24.06	24.23	24.15				
44-277	26.11	27.73	26.92				
44-278	24.17	43.49	33.83				

Finally, the truck allocation was performed by assigning units to the polygons. Table 5.10 shows the trucks allocation for source polygons.

Table 5.10 The trucks allocation for source polygons

777F		785D		793D	
Truck ID	No. of Polygons	Truck ID	No. of Polygons	Truck ID	No. of Polygons
44-2411	7	44-2511	7	44-273	1
44-2412	7	44-2512	4	44-276	1
44-2413	5	44-2513	7	44-277	1
44-2414	7	44-2514	7	44-278	1
44-2415	7	44-2515	3		
44-2416	7	44-2516	4		
44-2417	7	44-259	7		
44-2418	7				
44-2419	7				
44-2420	7				
44-2421	7				
44-2422	5				
44-2423	7				
44-2424	7				

44-248	7	
44-249	7	

5.5.2.5 Dozer Element

The dozer element represents three types of Caterpillar dozers used in the case study, either for spreading operation or for stripping operation.

A) Spreading dozer: The types used for spreading operation are D6T and D8T. Type D6T has two dozer units, distinguished by IDs given to them; the two units IDs are 44-311 and 44-312. Type D8T has three dozer units: 44-331, 44-332, and 44-333. Table 5.11 shows the input of the spreading dozer units.

Table 5.11 Input of the spreading dozer units

Input	D6T	D8T
Number of Dozers	2	3
Blade Capacity (m^3)	5.61	8.7
Ideal Production (hr/m^3)	300	450
Wheel Type	Track	Track
Grade Percent (%)	0	0
Material Type	Loose	Loose
Operator Skill	Excellent	Excellent
Visibility	Normal	Normal
Machine Transmission Factor	1	1
Operating Technique	Slot Dozing	Slot Dozing
Efficiency	0.9	0.9
Cost Rate ($/hr)	-	-
Working Hours per Day	13.5	13.5
Time Between Breakdowns (hr)	500	500
Time to Fix (hr)	10	10

First for the spreading dozer, the value of the ideal production was based on a constant distance of spreading of 50 m, dozing with a semi-universal blade. The values were taken from the Caterpillar Performance Handbook (2010). However, no database was used because there was no data available for dozers in general, especially distance of spreading and ideal productions; hence, using the database makes no change to the simulation performance, and using fixed values is more suitable.

Due to the insufficient information about efficiency and the working conditions of the spreading dozers, they were all assumed according to the most common values. During the working days that the case study covers, no breakdown incidents were recorded, so it is better to choose a high number for breakdowns so that no breakdowns occur during the simulation.

The total working hours per day were assumed to be 13.5 hours (as discussed in the excavator element section). Again, due to the records confidentiality with the contracting company Graham, and since there is no actual data to compare the simulation results with, the cost rate was not involved. Finally, the rest of the input is machine standards taken from the manufacturer (Caterpillar, 2010).

There is no data available for spreading dozer allocation, except that D6 and D8 dozers are used for spreading operations. Spreading dozer allocation was performed by assigning units to the polygons. Table 5.12 shows the spreading dozers allocation for placement polygons.

Table 5.12 The spreading dozer allocation for placement polygons

Spreading Dozers			
D6T		D8T	
Type	No. of Polygons	Type	No. of Polygons
44-311	2	44-331	2
44-312	2	44-332	2
		44-333	2

B) Stripping dozer: The types used for spreading operation are D9T and D10T. Type D9T has four units: 44-241, 44-242, 44-243, and 44-244. Type D10T has one unit only: 44-251. Table 5.13 shows the input of the stripping dozer units.

Table 5.13 Input of the stripping dozer units

Input	D9T	D10T
Number of Dozers	4	1
Blade Capacity	13.5	18.5
Amount to Doze Before Requesting an Excavator (m^3)	1	1
Time to Strip One Meter Square (min)	0.1	0.1
Efficiency	0.9	0.9
Cost Rate ($/hr)	-	-
Working Hours per Day (hr)	13.5	13.5
Time Between Breakdowns (hr)	500	500
Time to Fix (hr)	10	10

First for the stripping dozer, the values of the time to strip one meter square and the amount to doze before requesting an excavator were assumed. Even if these values appeared too small, these assumptions were deemed acceptable by Alberta superintendents working with Graham (2011). The reason for assuming smaller values is that stripping dozer incorporation should be enhanced in future development of the template, thus it is better to limit or minimize the stripping dozer's impact on the overall simulation results.

Due to the insufficient information about efficiency, it was assumed according to the most common values. During the working days that the case study covers, no breakdown incidents were recorded, so it is better to choose a high number for breakdowns so that no breakdowns occur during the simulation.

The total working hours per day were assumed to be 13.5 hours (as discussed in the excavator element section). Again, due to the records confidentiality with the contracting company Graham, and since there is no actual data to compare the simulation results with, the cost rate was not involved. Finally, the blade capacity is a machine standard taken from the manufacturer (Caterpillar, 2010).

There is no data available about stripping dozer allocation, except that D9 and D10 dozers are used for stripping operations. Stripping dozer allocation was

performed by assigning units to the polygons. Table 5.14 shows the stripping dozers allocation for source polygons.

Table 5.14 The stripping dozer allocation for source polygons

Stripping Dozers			
D9T		D10T	
Truck ID	No. of Polygons	Truck ID	No. of Polygons
44-341	1	44-351	1
44-342	1		
44-343	1		
44-344	1		

5.5.2.6 Road Element

Two road elements represent the only hauling route that connects the source and the placement. One road element represents the hauling path, and the other represents the return path. Table 5.14 shows the input of the road elements.

Table 5.15 Input of the road elements

Input	Road 1 (hauling)	Road 2 (return)
Number of Segments	1	1
Segment Length (m)	3250	3250
Rolling Resistance (RR) (%)	2	2
Grade Resistance (GR) (%)	1	-1
Maximum Allowable Speed (km/hr)	100	100
Attitude Factor	1	1
Stopping Sight Distance (SSD) (m)	100	100

As discussed previously, the distance (hauling route) between the source entrance and placement dump is 3750 m, but this distance includes the distance within the placement location, which is the dimension of the placement element's unit areas (dimension of 500 m^2). So, the road element's length is the deduction of these two values, which results in 3250 m.

Due to the insufficient information about the number of the road's segments, hauling route's conditions (RR, GR, and attitude), stopping sight distance, and maximum allowable speed, they were assumed according to the most common values, excluding the speed. The maximum allowable speed was assumed at 100 km/hr, so that no restriction is applied to the truck's speed, because it is impossible for the speed of the aforementioned tuck types to reach 100 km/hr.

Finally, in order to test different estimating scenarios, both the empirical method and the mathematical calculation method were chosen to estimate traveling time.

5.5.2.7 Intersection and Branch Elements

Although there is not sufficient information about intersection(s) location and specifications, if any, in the project, and due to the information obtained from interviewing some superintendents who worked on this project for Graham (2011), confirmed the existence of an intersection, it is better to include an intersection in the model, even with assumed specifications. Table 5.16 shows the input of the intersection element.

Table 5.16 Input of the intersection element

Time Intervals of North Traffic (min)	5 Modeled as Exponential Distribution
Time Intervals of South Traffic (min)	5 Modeled as Exponential Distribution
Time Intervals of West Traffic (min)	5 Modeled as Exponential Distribution
Time to Cross	1

The values in the table were assumed, and the intersection is assumed to be a stop-sign intersection. For the branch element inside the intersection, the directions of the source element and the placement element were set at west and south, respectively.

5.6 RESULTS AND ANALYSIS

Since there are two methods for trucks speed input (Chart and VIMs) and two methods for travel time calculation (Mathematical and Empirical), there are four resulting scenarios: estimating travel time mathematically adopting the speed from manufacturer's (Caterpillar) charts, estimating travel time empirically adopting the speed from manufacturer's (Caterpillar) charts, estimating travel time mathematically adopting the speed from the VIMs historical data, and finally estimating travel time empirically adopting the speed from the VIMs historical data.

In this section, the four scenarios' results will be illustrated, analyzed and discussed comparatively to reach an overall general conclusion that evaluates the reliability and practicality of the template.

5.6.1 Soil Material Output

Although there are four scenarios, the amount of processed soil material remains the same. Thus, the soil material results are identical for the four scenarios, so there is no need for comparative discussion. Table 5.17 shows the general output for processed soil material.

Table 5.17 The general output for processed soil material

Muskeg Layer	
Muskeg Actual Reclamation (%)	1
Muskeg Required Reclamation (%)	1
Total Actual Placement(s) Muskeg Volume (m^3)	281476.67
Total Required Placement(s) Muskeg Volume (m^3)	282000
Total Source(s) Muskeg Volume (m^3)	281476.67
Secondary Layer	
Secondary Actual Reclamation (%)	1
Secondary Required Reclamation (%)	1
Total Actual Placement(s) Secondary Volume (m^3)	16469.39
Total Required Placement(s) Secondary Volume (m^3)	16600
Total Source(s) Secondary Volume (m^3)	16469.39
Overall Material Output	
Total Actual Reclamation (%)	1
Total Required Reclamation (%)	1
Total Actual Placement(s) Volume (m^3)	297946.06
Total Required Placement(s) Volume (m^3)	298600
Total Source(s) Volume (m^3)	297946.06

As mentioned previously, the current phase of the project that the case study covers required that the hauled soil layer material be dumped separately in the placement location. Therefore, no real placement order was performed. As a result, all the excavated material was dumped in the placement location directly, which means 100% actual reclamation.

5.6.2 Equipment Output

Unlike the soil material output, the equipment output is not unified; it is differentiated depending on the scenario presented. Before analyzing the results of each scenario, it is worthy to mention that there are many contradictions between VIMs data parameters and the project reports, such as the truck allocation, number of loads, and possibly the quantities of material hauled. For example, according to project reports, 793D trucks only work on the 10th of December (the last day of the case study). However, VIMs data show that they work on December 3rd, 4th, 5th, 6th, 7th and 10th. Another example is the number of truck loads: VIMs shows 4620 including the 793D loads, and the project reports show 4930 loads. In addition to that, the hauled material volume will never be calculated through the VIMs data because the VIMs contain payloads only, without material volume or type to know the exact density. As a result of these discrepancies, it should be noted that project reports will be adopted in any case of contradiction.

The main parameters in which the output of the different scenarios will be compared with the actual results are the truck loads, which can be also referred to as cycles, and the case study's duration. As it is mentioned in the input section, cost is not included due to record confidentiality with Graham. The number of truck loads is 4930 loads, and the actual duration of the project is about 9 days, with 13.5 working hours per day in average, which means 121.5 hours project duration.

The 9-day project duration results after omitting the working time performed for the LFH material removal in total, and the muskeg material removal in Polygon 21. Through the ratio of the truck loads performing these two processes to the total truck loads multiplied by the case study duration (10 days), it was found that these two processes take approximately 1 day; therefore, the total project duration is 9 days. The breakdown of the value of working hours per day was discussed previously (see the excavator element section).

Since there are four different scenarios, there are four different results. Table 5.18 shows the final overall equipment output for the four scenarios divided by input type (Caterpillar charts or VIMs data) with the corresponding calculation method (Mathematical or Empirical).

Table 5.18 Final overall equipment output for the four scenarios

	Mathematical - Charts	Mathematical - VIMs	Empirical - Charts	Empirical - VIMs
Excavators				
Total Excavator Time (hr)	561.32	730.95	565.8	653.49
Excavators Actual Production (m^3/hr)	530.8	407.61	526.6	455.93
Number of Cycles/Loads	5022	4904	5140	4922
Trucks				
Total Trucks Time (hr)	2113.36	2951.07	1818.37	2615.76
Trucks Actual Production (m^3/hr)	140.98	100.96	163.85	113.9
Number of Cycles/Loads	5022	4904	5140	4922
Dozers				
Total Dozers Time (hr)	1042.19	1091.72	1042.17	1042.58
Dozers Actual Production (m^3/hr)	285.88	272.91	285.89	285.78
Number of Cycles/Loads for Spreading Dozers	5022	4904	5140	4922
Number of Cycles/Loads for Stripping Dozers	5	5	5	5
Equipment Overall				
Approximate Overall Actual Production (m^3/hr)	2375.76	2145.09	2376.54	2370.28
Project Duration (hr)	125.41	138.9	125.37	125.7
Project Equipment Total Working Time (hr)	3716.85	4773.74	3426.33	4311.84

As the table shows, the outputs of the scenarios are close. Starting with truck loads, the closest truck load output is the one resulting from VIMs data input calculated empirically, which is 4922 loads. This means only 0.16% of error. The farthest output is the one resulted from Caterpillar charts input calculated also empirically, which is 5140 loads. This means 4.26% of error, which is acceptable. The rest of the truck load outputs are 5022 loads and 4904 loads resulting from Caterpillar charts input and VIMs data input respectively, and both calculated mathematically. This means 1.87% and 0.53% of error, respectively.

For the project duration, except for the output resulting from the VIMs data calculated mathematically, the difference between project duration outputs for the scenarios is very minimal. The project duration outputs for those three are 125.41 hrs (9.29 days), 125.37 hrs (9.287 days) and 125.7 hrs (9.31 days), resulting respectively from Caterpillar charts input calculated mathematically, and Caterpillar charts and VIMs data input both calculated empirically. This means only 3.22%, 3.19%, and 3.46% of error respectively. The farthest project duration output resulted from the remaining scenario, the Caterpillar charts input calculated mathematically, which is 138.9 hrs (10.29 days). This means 14.32% of error, which is still acceptable.

It should be mentioned that in all scenarios, trucks of type 793D were never used in the model; this is due to the excavation sequence of the polygons and 793D trucks allocation, in which, according to the project reports, 793D trucks were

assigned to Polygon S21 only and the dirt material of Polygon S21 was being excavated on the last day (10th of December). In addition this, and as it is mentioned in a previous section, the truck allocation in the project reports and the VIMs was daily-based, not polygons-based, thus, a lot of trucks of another type were assigned to Polygon S21. Therefore, Polygon S21 was excavated last while a lot of other trucks were available after being done with hauling from other polygons, and the template's scope is to operate/call the equipment that are waiting on the ground rather than calling new trucks that have never been used in the model. As a result of the previous explanation, the template's model has called the available 777F and 785D trucks waiting to be loaded rather than calling 793D trucks that have never been worked because they were assigned only to Polygon S21.

Additionally, according to the VIMs data, the number of truck loads for 793D trucks is 16 loads, which is very small compared to the total number of truck loads (4930); hence, it can be neglected. Also, according to VIMs, the total working time of the 793D truck fleet is 14.2 hrs; however the waiting time is 6.9 hrs. This means that almost 50% of the time that the 793D truck fleet existed on site ground it didn't perform any work but waiting; in other words, the optimization of 793D truck fleet is very low. All in all, the significance of 793D truck fleet in the actual project is very minimal and can be neglected or can be substituted by the 777F and 785D truck fleets; hence, it is acceptable that the 793D trucks were not used in the template model.

According to some superintendents and specialists working for Graham (2011), the rest of the final overall outputs are adequate. The final results of each equipment unit for all scenarios are illustrated extensively in Appendix (B). These final results include, but are not limited to: productions, number of cycles (loads), times (waiting, working, and delayed), and the quantity of dirt material processed.

5.7 MODEL'S LIMITATIONS

Although the template offered very adequate results, like any other method or approach, it still has some limitations. Such limitations can be eliminated or controlled through advancing some features in the template in general, adding some components to the template, or even developing a new template that embraces this template's scope and structure. The limitations that require the aforementioned mitigations are discussed in the following chapter (Chapter 6).

Regarding the case study's model specifically and the template in general, when the input criteria are not machine manufacturing standards (weight, capacity, etc.), the modeler (practitioner) has to make many assumptions if there is not sufficient information and/or historical data for the input process. This results in less model reliability.

To avoid using assumptions, in addition to the data already used for some input aspects in the case study, the practitioners need to collect data for the following input aspects:

- Excavators:
  1) Excavator bucket cycle time.
  2) Average angle of swing for an excavator.

- Trucks:
  1) Truck's deployment details (IDs and types), by which excavator it is loaded, the date, and which excavation and placement polygons it goes to (e.g.: 777F: 44-2411 was loaded by Ex1200: 41-1601 in W4 Pol. 25 and has dumped in SP4 Pol. 4 on 12/1/2011).
  2) The approximate distance for a truck to reach maximum speed (average of loaded and empty).
  3) Truck speed on the excavation/placement site.
  4) Dumping time on the placement site.

- Dozers:
  1) Dozer's deployment details (IDs and types); polygon name that is assigned to (excavation polygons when it is a stripping dozer and placement polygons when it is a spreading dozer), the date, the dirt type, and the dirt

volume stripped/spread. (e.g.: D8T: 44-311 spread 2000m^3 of LFH in SP4 Pol.4 at 12/1/2011).

2) Distance of spreading for a spreading dozer, or spreading dozer's production in ideal conditions, or the actual conditions by setting the production factors in the input list of the spreading dozers to one (1).

3) Time for a stripping dozer to strip 1 m^2.

- Equipment in general:

   1) Time between breakdowns and time for maintenance/fix.

   2) Efficiency — actual working minutes per hour. In other words, how much time the equipment practically works when it is available on site excluding queuing (waiting) and breakdowns (including coffee breaks, site meetings, miscellaneous breaks, etc.).

- Roads and Intersections:

   1) Haul Route specifics (GR, RR, number of segments, segments' lengths), including curves specifics (radius and superelevation), if any.

   2) Intersection locations if any.

   3) Time for a vehicle to cross the intersection.

   4) The frequency of the traffic flow (time interval between arrivals), taking into consideration whether it is a 4-way or 3-way intersection.

It should be noted that some of the data collected will be used in input criteria that can be modeled as a probability distribution in the template. Finally, some of the data collection requirements mentioned above are not only used for input purposes, but can also be used for increasing the precision of the output and verifying the results.

5.8 SIMULATION VALIDATION

After validating the reclamation template using actual existing project process and data, the reclamation template will be validated via another simulation tool. This simulation tool should have been verified and approved by academics and practitioners to be used for any construction operation in general, including earthwork operations. The best choice is the origin of the reclamation template, the general purpose template of Simphony.NET.

This validation can be done by building two simulation models based on unified input data; the first model is constructed using the reclamation template's environment and the other model using the general purpose template's environment. The output of the two models will be compared to give a clear vision about the credibility of the reclamation template, academically. Identical results or results with minimal error indicate high validity.

5.8.1 Model's Input

In order to make a straight-forward model that can be tracked and understood easily, many input items of the reclamation template are either assumed or neutralized (set to one or zero). These input items have no direct effect on the aforementioned output items such as TKPH for trucks, or they represent factors/ratios which are used in formulas such as equipment efficiency and swelling factors.

The handled material dirt type is secondary only, the equipment used in the model is one excavator, 3 trucks of the same type and one spreading dozer, the calculation method for travel time estimation is the Empirical method. Finally, the model has no intersections. Table 5.19 shows the input of the validation model.

Table 5.19 Input of the validation model

Soil Material	
Volume to excavate and spread (m^3)	200
Road	
Distance (km)	5
Excavator	
Bucket Capacity (m^3)	2
Bucket Cycle Time (min)	0.75
Trucks	
Capacity (m^3)	20
Truck Speed loaded (km/hr)	25
Truck Speed Empty (km/hr)	45
Dumping Time (min)	0.5
Dozer	

Ideal Production (m^3/hr)	100

5.8.2 Model's Layout

The model using the reclamation template very simply consists of one source element, one placement element, two roads connecting them, one excavator element, one truck element, one dozer element, and one reclamation element to show the final results. Figure 5.7 shows the model layout in the reclamation template.
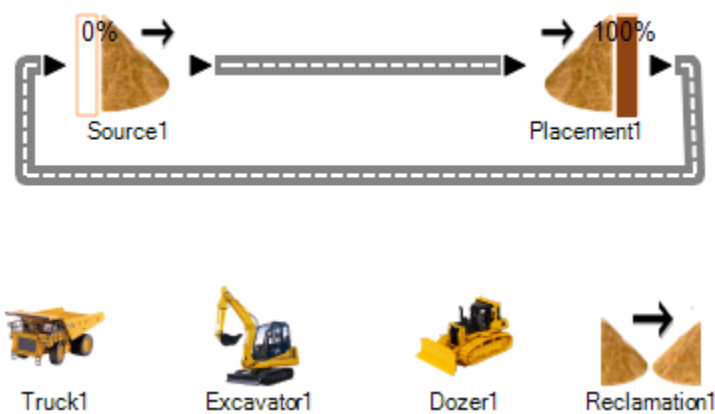
Figure 5.7 The model layout in reclamation template

However, the model using general purpose template consists of one create element, and three resource elements along with three file elements, three capture elements and three release elements. These elements combined represent equipment (excavator, trucks, and dozer). In addition to that, four execute elements incorporate codes for calculation formulas, one generator element, two counters for counting the entities, two delete elements to terminate entities, and four task elements representing the following activities: excavating, hauling and

dumping, returning, and spreading. Finally, sixty-three (63) comment elements are used to store and visualize the input and output of the model. Figure 5.8 shows the model layout in the general purpose template of Simphony.NET.
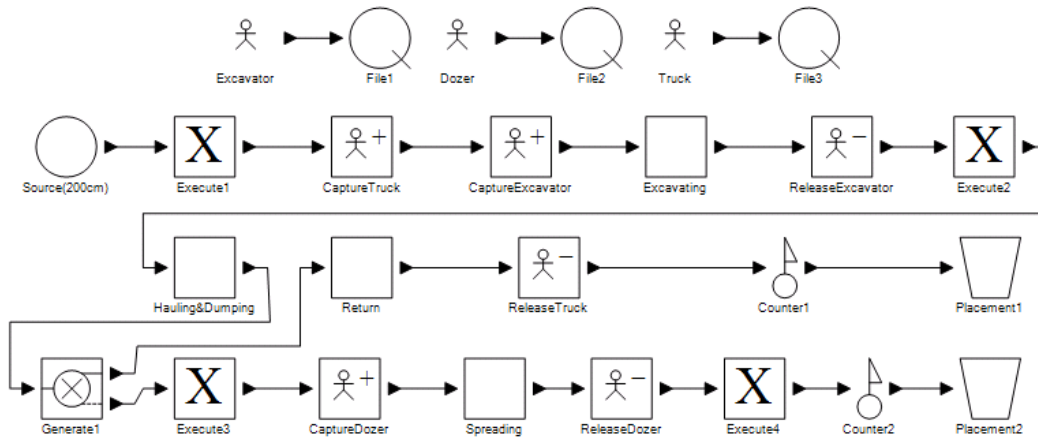
Figure 5.8 The model layout in general purpose template of Simphony.NET

5.8.3 Output Comparison

Before going into the validation results analysis, the output validation criteria should be identified. The quantity of material handled, number of cycles for each equipment, equipment production, and different time types such as waiting time and working time are the result items that should be verified. Figure 5.9 shows the output of the reclamation template via report, and Figure 5.10 shows the output of the general purpose template via adding sixty three comment elements. For comparison purposes, Table 5.20 shows the output analysis of the two models.

Figure 5.9 The output of the reclamation template

Figure 5.10 The output of the general purpose template

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Table 5.20 The output analysis of the two models

Output	Reclamation Template	General Purpose Template
Material		
Amount Excavated (m^3)	200	200
Amount Hauled (m^3)	200	200
Amount Spread (m^3)	200	200
Excavator		
Number of Cycles	10	10
Total Loading Time (hr)	1.25	1.25
Total Waiting Time (hr)	0.21	0.19
Total Working Time (hr)	1.46	1.44
Total Production (m^3/hr)	137.14	139.54
Trucks		
Number of Cycles	10	10
Total Travel Time (hr)	3.19	3.19
Total Waiting Time (hr)	0	0
Total Working Time (hr)	4.44	4.44
Total Production (m^3/hr)	45	45
Dozer		
Number of Cycles	10	10
Total Spreading Time (hr)	1.39	1.39
Total Waiting Time (hr)	0.08	0.06
Total Working Time (hr)	1.47	1.45
Total Production (m^3/hr)	135.85	138.2
Overall		
Project Duration (hr)	1.81	1.78
Total Production (m^3/hr)	110.77	112.86

The results of the two models are very close and many are identical. The main variance between the results is in waiting time of the excavator and the dozer, which is reflected on the total working time and production of the excavator and the dozer, the project duration, and the overall production. Based on that, the error percentage that should be considered in validation is waiting time, in which the result of the general purpose template is the correct one.

The error of the excavator waiting time variance between the reclamation template and the special purpose template is approximately -10.5%, the truck waiting time error is approximately 0, and the dozer waiting time error is approximately -1.4%. Since the rest of the output items are built on the waiting time, the error of these items will get smaller, e.g. error of project duration is only -1.6%, and the total overall production is only 1.9%.

5.8.4 Conclusion

Most of the output items in the two models were identical except for the waiting time of the excavator and the dozer. Despite of this differentiation, the error percentage was very low. The possible reason behind this variance is that the queuing procedure in the general purpose template is slightly different than that of the reclamation template; hence, if resources are modeled separately as independent entities, the results would possibly be closer.

It is worth mention that building the model in the reclamation template took about 10 minutes, however, it took around 3-4 hours to build it in the general purpose template due to coding and sorting out the best element arrangement.

CHAPTER 6 CONCLUSION

6.1 RESEARCH CONCLUSIONS

This research presented a special purpose simulation template to model earthwork operations of the reclamation process. The research tried to reflect the reality of reclamation earthwork operations as much as possible, and make the simulation tool as easy as possible for practitioners to use.

The primary objective and sub-objectives of this research were outlined in Chapter 4, which also embraced the work of Chapter 1 and Chapter 3; the objective accomplishments were examined and the template was validated successfully in Chapter 5.

According to some practitioners working for Graham (2011), who have observed the template's performance, the template is both practical and technically sound; hence, it can be used as a planning tool within the construction industry. Use of the template saves time and effort by minimizing spreadsheet use. Also, it is technically credible as the number of assumptions has been minimized, and data is easily implemented, even when data is coming from the site, during work. In addition, it is very useful to examine/control scope changes by visualizing new scenarios during the construction work, or testing different scope scenarios during preliminary and conceptual planning, or feasibility studies. It may even be used as

a tool for decision-making support during the bidding period by helping in assessing possible risks.

This simulation tool, combined with existing earthmoving simulation tools, would work effectively towards better, more efficient planning for the earthwork operations of reclamation.

6.2 FUTURE RECOMMENDATIONS

The future recommendations are classified into two levels: improvements of the reclamation earthwork template, and future research.

6.2.1 Improvements of the Reclamation Earthwork Template

The performance and the implementation of the template would be enhanced through the following improvements:

1) Integrating 3D CAD with Simphony.NET 4.0 for the source and placement elements.

2) Amending the input method for material specifications to be via database.

3) Changing the input method of the equipment when it is related to the machine standards (weight, capacity, etc.) to be related to the equipment type, while keeping the unique input in line with the equipment piece.

4) Adding the working calendar to the template and amending the time output based on the calendar.

5) Increasing the role of the stripping dozers by enhancing the interaction between them and the excavators, and adding more attributes to them.

6) Organizing the source elements allocated to the excavator and stripping dozer, and the placement elements allocated to the spreading dozer by adding a priorities list to the input list of the aforementioned equipment, similar to the one that already exists in the truck's input list.

6.2.2 Future Research

Several future research areas could be explored:

1) Modeling the earthwork operations of reclamation using the High Level Architecture (HLA) simulation technique.

2) Studying the impact of the weather and climate on the reclamation earthwork operations, and incorporating the study with the existing template.

3) Studying the effect of the trucks' tires on the earthwork operations and incorporating the study with the existing template, since the TKPH output that exists in the template doesn't have any effect on speed, time or production.

4) Studying the availability and efficiency aspects of the equipment and incorporating the study with the existing template, since the efficiency is represented as a factor that is approximated or assumed by the practitioner in the template.

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The following table illustrates the allocation of the equipment units (excavators, trucks, and stripping dozers) for each polygon:

	Excavators			Trucks			Stripping Dozers	
	Ex850	Ex1200	Ex1900	777F	785D	793D	DT9	DT10
Polygon 4	41-154, 41-15002	41-1601, 41-1602	41-1702	44-2411, 44-2412, 44-2413, 44-2414, 44-2415, 44-2416, 44-2417, 44-2418, 44-2419, 44-2420, 44-2421, 44-2422, 44-2423, 44-2424, 44-248, 44-249	44-2511, 44-2512, 44-2513, 44-2514, 44-2515, 44-2516, 44-259	-	-	44-351
Polygon 23	41-154, 41-15002, 41-15006	41-1601, 41-1602	-	44-2411, 44-2412, 44-2413, 44-2414, 44-2415, 44-2416, 44-2417, 44-2418, 44-2419, 44-2420, 44-2421, 44-2422, 44-2423, 44-2424, 44-248, 44-249	44-2511, 44-2512, 44-2513, 44-2514, 44-2515, 44-2516, 44-259	-	44-342	-
Polygon 24	41-154, 41-15002	41-1601, 41-1602	41-1702	44-2411, 44-2412, 44-2413, 44-2414, 44-2415, 44-2416,	44-2511, 44-2512, 44-2513,	-	44-344	-

				44-2417, 44-2418, 44-2419, 44-2420, 44-2421, 44-2422, 44-2423, 44-2424, 44-248, 44-249	44-2514, 44-2515, 44-2516, 44-259			
Polygon 25	41-154, 41-15002, 41-15006	41-1601	-	44-2411, 44-2412, 44-2413, 44-2414, 44-2415, 44-2416, 44-2417, 44-2418, 44-2419, 44-2420, 44-2421, 44-2422, 44-2423, 44-2424, 44-248, 44-249	44-2511, 44-2512, 44-2513, 44-2514, 44-2516, 44-259	-	44-343	-
Polygon 27	41-154	41-1602	41-1702	44-2411, 44-2412, 44-2413, 44-2414, 44-2415, 44-2416, 44-2417, 44-2418, 44-2419, 44-2420, 44-2421, 44-2422, 44-2423, 44-2424, 44-248, 44-249	44-2511, 44-2513, 44-2514, 44-259	-	44-341	-
Polygon S21	-	-	41-1702	44-2411, 44-2412, 44-2414, 44-2415, 44-2416, 44-2417, 44-2418, 44-2419, 44-2420, 44-2421, 44-2423, 44-2424, 44-248, 44-249	44-2511, 44-2512, 44-2513, 44-2514, 44-259	44-273, 44-276, 44-277, 44-278		

| Polygon S24 | - | - | 41-1702 | 44-2411, 44-2412, 44-2414, 44-2415, 44-2416, 44-2417, 44-2418, 44-2419, 44-2420, 44-2421, 44-2423, 44-2424, 44-248, 44-249 | 44-2511, 44-2512, 44-2513, 44-2514, 44-259 | - | |

APPENDIX B: FINAL RESULTS OF EACH EQUIPMENT UNIT FOR

ALL SCENARIOS

The following tables illustrate the final results of each equipment unit for all scenarios:

A) When it is calculated empirically using VIMs data:

    1) Dozers' (spreading and stripping) results:

Spreading Dozers				Stripping Dozers			
D6T		D8T		D9T		D10T	
Type	Loads	Type	Loads	Type	Loads	Type	Loads
44-311	758	44-331	1136	44-341	1	44-351	1
44-312	758	44-332	1133	44-342	1	Total Loads are 5	
Total D6T	1516	44-333	1137	44-343	1		
		Total D8T	3406	44-344	1		
Total Loads are 4922				Total D9T	4		

    2) Trucks' results:

777F		785D		793D	
Type	Loads	Type	Loads	Type	Loads
44-2411	273	44-2511	213	44-273	-
44-2412	278	44-2512	157	44-276	-
44-2413	236	44-2513	201	44-277	-
44-2414	284	44-2514	181	44-278	-
44-2415	174	44-2515	160	Total 793D	-
44-2416	238	44-2516	140		
44-2417	244	44-259	189		
44-2418	259	Total 785D	1241		
44-2419	240				
44-2420	233				
44-2421	205				
44-2422	230	Total Loads are 4922			
44-2423	149				
44-2424	206				
44-248	210				

44-249	222
Total 777F	3681

3) Excavators' results:

Ex850		Ex1200		Ex1900	
Type	Loads	Type	Loads	Type	Loads
41-154	745	41-1601	743	41-1702	1287
41-15002	745	41-1602	749		
41-15006	653	Total Ex1200	1492		
Total Ex850	2143	Total Loads are 4922			

B) When it is calculated empirically using Caterpillar charts:

1) Dozers' (spreading and stripping) results:

Spreading Dozers				Stripping Dozers			
D6T		D8T		D9T		D10T	
Type	Loads	Type	Loads	Type	Loads	Type	Loads
44-311	791	44-331	1184	44-341	1	44-351	1
44-312	792	44-332	1188	44-342	1	Total Loads are 5	
Total D6T	1583	44-333	1185	44-343	1		
		Total D8T	3557	44-344	1		
Total Loads are 5140				Total D9T	4		

2) Trucks' results:

777F		785D		793D	
Type	Loads	Type	Loads	Type	Loads
44-2411	350	44-2511	181	44-273	-
44-2412	345	44-2512	170	44-276	-
44-2413	279	44-2513	127	44-277	-
44-2414	348	44-2514	17	44-278	-
44-2415	338	44-2515	-	Total 793D	-
44-2416	278	44-2516	-		
44-2417	277	44-259	1		
44-2418	273	Total 785D	496		
44-2419	281				
44-2420	275	Total Loads are 5140			
44-2421	281				

44-2422	270
44-2423	271
44-2424	261
44-248	266
44-249	251
Total 777F	4644

3) Excavators' results:

Ex850		Ex1200		Ex1900	
Type	Loads	Type	Loads	Type	Loads
41-154	779	41-1601	778	41-1702	1343
41-15002	778	41-1602	778		
41-15006	684	Total Ex1200	1556		
Total Ex850	2241	Total Loads are 5140			

C) When it is calculated mathematically using VIMs data:

1) Dozers' (spreading and stripping) results:

Spreading Dozers				Stripping Dozers			
D6T		D8T		D9T		D10T	
Type	Loads	Type	Loads	Type	Loads	Type	Loads
44-311	811	44-331	1138	44-341	1	44-351	1
44-312	796	44-332	1093	44-342	1		
Total D6T	1607	44-333	1067	44-343	1	Total Loads are 5	
		Total D8T	3298	44-344	1		
Total Loads are 4905				Total D9T	4		

2) Trucks' results:

777F		785D		793D	
Type	Loads	Type	Loads	Type	Loads
44-2411	264	44-2511	214	44-273	-
44-2412	266	44-2512	155	44-276	-
44-2413	230	44-2513	207	44-277	-
44-2414	271	44-2514	184	44-278	-
44-2415	169	44-2515	167	Total 793D	-
44-2416	227	44-2516	154		

44-2417	236	44-259	215	
44-2418	259	Total 785D	1296	
44-2419	237			
44-2420	244	Total Loads are 4905		
44-2421	198			
44-2422	229			
44-2423	144			
44-2424	202			
44-248	208			
44-249	225			
Total 777F	3609			

3) Excavators' results:

Ex850		Ex1200		Ex1900	
Type	Loads	Type	Loads	Type	Loads
41-154	747	41-1601	735	41-1702	1245
41-15002	747	41-1602	742		
41-15006	689	Total Ex1200	1477		
Total Ex850	2183	Total Loads are 4905			

D) When it is calculated mathematically using Caterpillar charts:

1) Dozers' (spreading and stripping) results:

Spreading Dozers				Stripping Dozers			
D6T		D8T		D9T		D10T	
Type	Loads	Type	Loads	Type	Loads	Type	Loads
44-311	772	44-331	1158	44-341	1	44-351	1
44-312	775	44-332	1158	44-342	1	Total Loads are 5	
Total D6T	1547	44-333	1159	44-343	1		
		Total D8T	3475	44-344	1		
Total Loads are 5022				Total D9T	4		

2) Trucks' results:

777F		785D		793D	
Type	Loads	Type	Loads	Type	Loads
44-2411	298	44-2511	196	44-273	-

44-2412	300	44-2512	182	44-276	-
44-2413	245	44-2513	164	44-277	-
44-2414	295	44-2514	143	44-278	-
44-2415	296	44-2515	111	Total 793D	-
44-2416	298	44-2516	66		
44-2417	246	44-259	41		
44-2418	243	Total 785D	903		
44-2419	243				
44-2420	241				
44-2421	240				
44-2422	236				
44-2423	238	Total Loads are 5022			
44-2424	237				
44-248	232				
44-249	231				
Total 777F	4119				

3) Excavators' results:

Ex850		Ex1200		Ex1900	
Type	Loads	Type	Loads	Type	Loads
41-154	750	41-1601	760	41-1702	1304
41-15002	763	41-1602	760		
41-15006	670	Total Ex1200	1520		
Total Ex850	2198	Total Loads are 5022			