AN ADVISORY SYSTEM FOR SCRAPER SELECTION

A Thesis

by

JOHN CHARLES MAYFIELD

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2004

Major Subject: Construction Management

AN ADVISORY SYSTEM FOR SCRAPER SELECTION

A Thesis

by

JOHN CHARLES MAYFIELD

Submitted to Texas A&M University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Approved as to style and content by:

Neil Eldin (Chair of Committee)	Nancy Holland (Member)
Anne Nichols (Member)	James Smith (Head of Department)

May 2004

Major Subject: Construction Management

ABSTRACT

An Advisory System for Scraper Selection. (May 2004)

John C. Mayfield, B.B.A., Texas A&M University

Chair of Advisory Committee: Dr. Neil Eldin

Scrapers are useful construction equipment when hauling distances range between 500 to 3000 feet. When preparing an estimate for an earthmoving project utilizing scrapers, the capacity of the scraper and the cycle time for the given project conditions must be calculated. Since travel time varies widely based on the conditions of the haul road and the performance of the equipment, determining the most economical selection (size and model) and the correct number of scrapers and pushers is a rather tedious process. The calculation of travel time between the cut and fill zone involves repetitive calculations.

A spreadsheet-based interactive advisory system was created in order to facilitate these calculations and generate a list of recommended equipment. The system contains a scrapers database, performance charts, soil properties, and a user interface to solicit data that is specific to the project such as haul road surface conditions and characteristics. Data such as efficiency (minutes worked per hour) and hourly rates for operators and other workers can also be specified in the user interface. Once the user enters the quantity to be moved the application calculates the production rate, time required for the job, and the estimated unit cost for each scraper in the database. The system then produces a list of all scrapers, sorted in the order of shortest time or lowest unit price.

ACKNOWLEDGEMENTS

I would first like to thank God for making this all possible. I also owe a debt of gratitude to my esteemed thesis committee chair, Dr. Neil Eldin, for his encouragement and help with this project over the last year. Thanks also go to Dr. Nancy Holland and Dr. Anne Nichols, thesis committee extraordinaire, who were patient and encouraging throughout the writing and defense process. I must also thank Ms. Anne Lawrence and Ms. Corinne Hubach for their help in getting this project off the ground, accumulating data, and editing.

I would be remiss if I did not also extend sincere thanks to the entire faculty in the Department of Construction Science, for allowing me to pursue graduate studies in Construction Management, and for making those studies both enlightening and enjoyable. In particular, thanks to Dr. James Smith and Professor Leslie Feigenbaum for awarding me a research assistantship.

Finally, without the love and support of my wife, Tryphania, and the rest of my family, I could not have survived the first semester of graduate school, much less conducted this research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Scrapers are useful earthmoving machines, as they are independently capable of excavating, hauling, and placing soil. Although neither as effective as excavators (e.g., hoes and shovels) in excavating nor as efficient as trucks in hauling and placing soil, the fact that this one machine performs all three tasks makes it the equipment of choice when large quantities of soil need hauling for distances up to approximately 3000 feet.

To estimate time and cost of scrapers for an earthmoving operation, one considers the soil properties, conditions of haul road, and the performance characteristics of the scraper. Commonly, the haul road is divided into segments based on variations in the road grade resistance. The scraper's maximum travel speed is determined for each segment from the equipment performance chart such as the one shown in Fig. 1. Determining the most economical scraper among several available models for varying hauling conditions can be a rather tedious process.

Purpose Statement

The purpose of this paper is to present an automated procedure to facilitate the selection of the most economical choice among scrapers available for a specific project. Such a computer-aided procedure can improve the effectiveness of field engineers and estimators as it facilitates data entries, eliminates the time necessary for calculating total

---

This thesis follows the style and format of the *ASCE Journal of Construction Engineering and Management*.

resistance, travel speeds, travel time, and accurately determines the operation's cost. The user could also perform "what if" scenarios to identify minimum cost.

The procedure consists of an Excel spreadsheet containing a database of necessary data such as soil characteristics and scraper data, including their performance charts. Although the entry of data required for creating the database may seem time consuming, entries are only input once when initiating the database.

Research Objective

The objective of this study was to develop a computer-aided application to facilitate selection of the most economical scraper from the available list. This application provides the user with cost and production rate of the recommended scraper.

Research Tasks

The above objectives will be achieved through the successful completion of the following tasks:

1. Obtain performance data for as many scrapers as possible and enter the data into an Excel database.
2. Design an Excel spreadsheet to perform the calculations necessary to estimate production rate and cost for a given scraper.
3. Define macros in the spreadsheet program to enable comparisons between scrapers in the database.

.

Scope, Assumptions and Limitations

The deliverable of this research is an interactive equipment selection advisory system, which facilitates comparison between the performance of different scrapers working under specified jobsite conditions. Scraper production is calculated using the estimation technique described by Peurifoy and Schexnayder (2002). The study will be limited to Caterpillar® scrapers and travel time will be calculated using the equipment performance charts contained in the Caterpillar Performance Handbook, 33rd edition. It is assumed that all scrapers work in conjunction with a pusher.

Methodology

An Excel workbook has been developed and consists of the following 7 individual worksheets. The first worksheet, *User Interface*, is the one in which the user will enter the project parameters and access the macros. The second worksheet, *Calculations*, is the location of calculations involved in estimating scraper production. The third worksheet, *Recommended*, is used to display the recommended selections, sorted in order of preference. The fourth worksheet, *Soil Properties*, contains the types and characteristics of the earth to be moved. The fifth worksheet, *Road Conditions*, contains the types and characteristics of the haul road. The sixth worksheet, *Scrapers*, is the database itself, containing performance characteristics of each scraper. The seventh worksheet, *Temp*, is a temporary location for data for new scrapers being added to the database.

Organization of Thesis

This report is divided into 7 chapters. Chapter I presents the problem statement, objectives, research tasks, and scope of the project. Chapter II contains an overview of the literature in the area of estimating production of construction equipment. Chapter III presents an explanation and illustration of scrapers themselves. The calculations necessary to estimate scraper production are detailed in Chapter IV. The spreadsheet package is presented in Chapter V. A comparison of manual calculations and system results is presented in Chapter VI. Chapter VII presents the conclusions from this project, along with suggestions for further work.

CHAPTER II

REVIEW OF LITERATURE

The literature review is divided into 3 sections. The first section deals with computer-aided programs used in earthmoving projects. The second illustrates other equipment-specific applications. Section 3 presents two other programs written for scraper production.

Computers in Earthmoving

Several attempts have been made to develop computer-aided tools to assist in equipment selection. For example, Alkass and Harris (1988) designed a system to aid in equipment selection for road construction. This system, ESEMPS, is an expert system. Expert systems function by asking the user a series of yes/no questions. As these questions are answered, a set of programmed rules allow the system to guide the user to the “correct answer”. This system is linked to a set of external databases which contain information on machines, earth types, etc. The system also calculates projected costs.

Amirkhanian and Baker (1992) developed an expert system specifically geared toward equipment selection. Their system, based in VP Expert, asks a series of questions about project conditions and then recommends the type and number of pieces of equipment needed. Equipment choices include dozers, scrapers, excavators and trucks. The results are presented in spreadsheet form. The rules for this system were developed from a combination of interviews with earthmoving experts and equipment manufacturers. The system is limited to projects between 10,000 and 4,000,000 bank cubic yards (BCY). According to the authors, the system compared favorably to selections made by experts in the field, but did not balance the fleet of chosen equipment, i.e. did not calculate the ideal number of trucks per excavator or scrapers per pusher.

Christian and Xie (1996) developed an expert system built upon a rating system for various types of equipment. A survey was sent out to experts in the field seeking input on what type of machine was best for a variety of projects and soil types. This information was compiled into a table that rated each type of equipment from 0 to 10 (10 being best) for each set of project parameters. The expert system asks a set of questions, and then uses the rating system to select the appropriate type and number of equipment.

Equipment Selection Programs

Other researchers have developed expert systems for a specific type of equipment. Touran (1990) developed an expert system to aid in selection of compactors. This system takes into account the type of soil, properties of the soil, and degree of compaction required. It assigns weights for the usefulness of up to 10 different types of compactors and uses these weights to recommend the best compactor given the project conditions. It also produces predictions on the number of passes required to achieve the desired level of compaction, as well as the projected speed and cost. This system was designed not only to aid in estimation, but also to help train new engineers.

Alkass and Aronian (1990) produced an expert system for concrete placement. This system was developed in order to improve upon previous work by including equipment selection in the decision process. Project parameters such as site conditions, equipment availability, time constraints, and concrete properties were taken into consideration when developing the rule base. The program was designed to select the best types of equipment to be used, match various types of equipment, and predict the rate of output in cubic yards per hour. This system compared favorably with results from actually completed projects.

Hanna (1994) created a similar system for crane selection. In this system, the most appropriate type and size of crane or derrick is selected based on project parameters such as heaviest lift, maneuverability, and job conditions. The program produces output which lists the best type of crane, as well as setup parameters such as number of lifts for a tower crane. The main focus of the system is to eliminate or reduce the need for expensive consultations with crane experts. Results of the program were positive, though limited by the available database.

Scraper Selection Programs

Clemmens and Willenbrock (1978) developed the SCRAPESIM computer simulation program to predict cost and time required to complete a given project. This system was designed upon a stochastic approach to an earthmoving problem, as opposed to the deterministic calculations in use at the time. Probability distributions for various cycle time events, such as loading and travel, were used to predict time values for these events. User input was flexible with respect to number and types of equipment, but limited in that common earth or rock were the only available soil types.

More recently, Kuprenas and Hankhaus (2000) produced a system called SSPE which would select the proper scraper for a given set of conditions. The user enters job conditions, job scope, and soil type. The system responds with a recommendation as to the best scraper to use, along with estimated production rates. The knowledge on which the system is based was determined from experts in the field. The system assumes certain characteristics, such as the efficiency (minutes worked per hour) and the travel speed during acceleration and deceleration to be constant.

One thing that all of the systems mentioned above have in common is that they are built on knowledge based systems which attempt to arrive at the best possible selection based on a set of criteria, presented to the user as a series of questions. This sort of system is appealing when it is likely that a novice estimator would be using it.

However, none of the above expert systems provide visible comparisons of all equipment included. The ability to alter parameter data is somewhat limited in these systems as well. This limits the usefulness of these systems because the user might already have a fleet of similar equipment. Even though the equipment in inventory is not the most efficient for the project at hand, it might still be the most economical just because it is there. The system described in this research is designed to provide comparisons between all the equipment in the database to help make the decision about whether to use the best choice as recommended by the system or another choice because of availability.

CHAPTER III

SCRAPERS

As mentioned in the introduction, scrapers are designed to excavate, haul, and place earth materials. The excavation site is separated into cut and fill areas. The cut area is that area from which earth is to be excavated. The fill area is that area where the excavated earth is to be deposited. As the scraper enters the cut area, the operator lowers the front edge of the bowl into the earth. As it moves forward, the front edge of the bowl scrapes the earth into the bowl itself. When the bowl has been filled to the maximum selected capacity, the front edge is raised. The scraper then carries on to the fill area, where an ejection mechanism pushes the earth out of the bowl. The operator then swings the machine around, drives back to the cut area, and begins the process again. The time taken by a single iteration of this process is known as the cycle time.

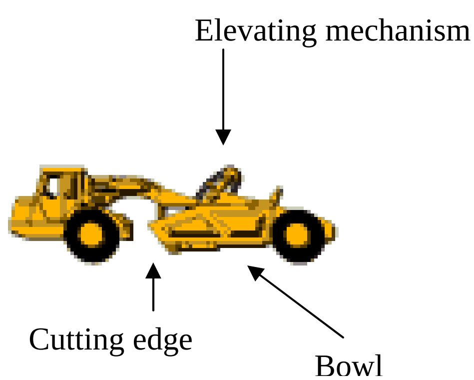
The cycle time can be broken into components. This is done to facilitate calculations. In addition to the travel times along various sections of haul road, the cycle time is made up of the load time, turn time at the fill, turn time at the cut, and load time. All of these variables will be used in calculating the estimate. They are listed in Table 1.

Table 1. Cycle time variables

T_S	Scraper cycle time
T_{Tr}	Travel time
T_{TF}	Turn time at fill
T_{TC}	Turn time at cut
T_L	Load time
T_D	Dump time

The cycle time, once calculated, is used to determine the optimum number of machines, or fleet balance, for the project. The process of calculating the cycle time, fleet balance, and cost of production are presented in the following chapter.

The scraper is meant to fill in the gap between dozers and excavators/dump trucks. These machines are not as efficient as dozers at moving earth for distances up to approximately 500 feet; nether are they as efficient as an excavator working with a group of trucks at hauling material for distances over approximately 3000 feet. For distances between these two extremes, however, scrapers tend to be the machine of choice. Figure 1 illustrates the loading mechanism of an elevating scraper.



http://www.ce.unlv.edu/cem/

Fig. 1. Loading mechanism of an elevating scraper.

Scrapers are wheeled vehicles, and hence capable of traveling at speeds of up to 33 miles per hour. However, this results in less traction. Scrapers, therefore, are usually loaded with the assistance of a push tractor (dozer). When the scraper enters the cut, the dozer comes up behind it and pushes it until the desired amount of material has been loaded. The scraper then heads off to the fill area, while the push tractor assists the next scraper in line.

There are four types of scrapers: pusher loaded scrapers, push-pull scrapers, elevating scrapers, and auger scrapers. Pusher loaded scrapers are those designed to be loaded with the help of a dozer, as discussed in the previous paragraph. These machines are effective when the haul grade is less than 5% and the return grade is less than 12% (Peurifoy & Shexnayder).

When project conditions necessitate a short haul distance, or the quantity of earth to be moved is relatively small, an elevating scraper might be a good choice. These machines are equipped with a mechanism which elevates the earth from the cutting edge to the bowl. This makes loading easier, and eliminates the need for assistance from a dozer. The extra weight of the elevating mechanism is a disadvantage. Elevating scrapers should also not be used in rocky material (Peurifoy & Shexnayder).

Push-pull scrapers are equipped with a cushioned push block. This enables two scrapers to attach to each other. The front scraper helps pull the rear scraper while the rear machine is loading, and the rear scraper pushes the front machine while the front machine loads. Connecting two scrapers together in this manner eliminates the need for a push tractor (Peurifoy & Shexnayder).

Auger scrapers, like elevating scrapers, are self-contained loading and hauling machines. An independently powered auger, located in the center o the bowl, carries material away from the cutting edge, thereby reducing cutting edge resistance. Unlike elevating scrapers, auger scrapers can be used in rocky material. The extra weight of the auger mechanism is a disadvantage (Peurifoy & Shexnayder).

CHAPTER IV

ESTIMATION TECHNIQUE

The method of calculating scraper production outlined in "Construction Planning, Equipment, and Methods" (Peurifoy & Schexnayder 2000) will be the basis of the spreadsheet. Estimation is performed by calculating the cycle time of the scraper and the capacity of the scraper, thereby computing the time it would take to move a given quantity of earth.

The first step is to calculate the actual carrying capacity of the scraper. The carrying capacity is a function of the maximum capacity for the scraper and a swell factor for the type of earth to be moved. Two different maximum capacities are typically listed for a given scraper. Heaped capacity it the maximum amount of material one could pile into the bowl of the scraper with a slope of 1:1 (Peurifoy & Schexnayder). Struck capacity is defined by Peurifoy & Schexnayder as "the volume a scraper would hold if the material was struck off even with the top of the bowl" (Peurifoy & Schexnayder, pg 207-8). The calculations start by using the heaped capacity. In the event that the calculated gross weight exceeds the maximum weight capacity of the scraper, the struck capacity will be used. In reality one could probably add more material without risking damage to the machine, but using the struck capacity gives the operator an easy method of visibly determining when to stop loading.

There are three factors to be taken into account when calculating the weight of material that can be moved in one trip. First, the weight of the earth to be moved is listed as pounds per bank cubic yard (BCY). When the earth is scooped up by the scraper, it will be loosened somewhat. Table 2 lists the weight of several different types of earth, and also the corresponding swell factor, expressed as a percentage. This factor allows for the loosening of the material. Second, consideration must be taken as to whether or not the scraper is equipped with an elevating mechanism. If the scraper being used is not elevated, the earth will undergo some compaction during the loading process. A factor of 10% factor is used to account for this. Third, the fact that it takes longer to load the last bit of material than the first needs to taken into account. There is, therefore, a trade-off between load time and capacity. A typical load growth curve is shown in Figure 2. For the example, a load-time capacity of 96% will be assumed. The following formula would be used:

$$Gross\ weight = CY_H * SF * \%CAP * CF * lb/BCY \tag{1}$$

where CY_H = heaped cubic yard capacity; SF = swell factor of the earth to be moved; %CAP = load-time capacity; CF = compaction factor (1.1 if the scraper is not elevated); and lb/BCY = weight of the material in pounds per bank cubic yard.

Table 2. Earth and rock properties

Material	Bank Wt (lb/cy)	Loose Wt (lb/cy)	Percent Swell	Swell Factor
Clay, dry	2700	2000	35	0.74
Clay, wet	3000	2200	35	0.74
Earth, dry	2800	2240	25	0.8
Earth, wet	3200	2580	25	0.8
Earth & Gravel	3200	2600	20	0.83
Gravel, dry	2800	2490	12	0.89
Gravel, wet	3400	2980	14	0.88
Limestone	4400	2750	60	0.63
Rock, well blasted	4200	2640	60	0.63
Sand, dry	2600	2260	15	0.87
Sand, wet	2700	2360	15	0.87
Shale	3500	2480	40	0.71

If the calculated gross weight is less than the maximum carrying capacity of the scraper, the heaped capacity is used. If the calculated gross weight is greater than the maximum carrying capacity of the scraper, the struck capacity is used. The load in BCY is calculated by one of the following two formulas.

$$L = CY_H * SF * \%CAP * CF \qquad (2a)$$

$$L = CY_S * SF * CF \qquad (2b)$$

where L = load in BCY; and CYS= struck cubic yard capacity.

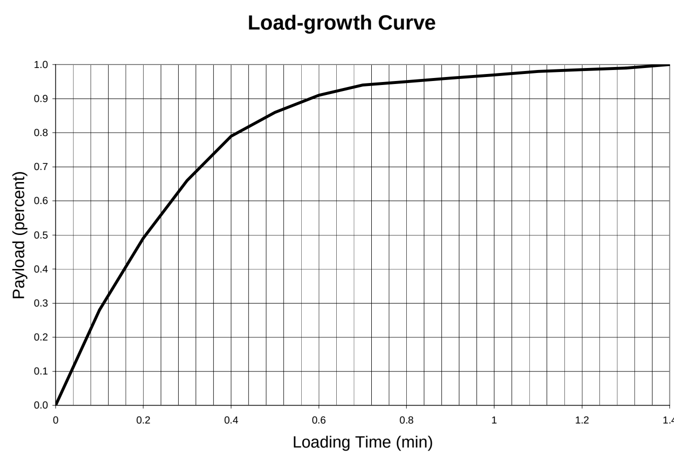


Fig. 2. Typical load growth curve

The second set of steps includes calculations for the cycle time for the scraper. As the example will show, the most tedious part of calculating the cycle time is determining the travel speeds over various portions of the haul road. Travel speeds are determined using one of two charts, the performance chart or the retarder chart. Two methods exist for this; the first uses a combination of vehicle weight and required power, while the second uses total resistance. The total resistance is the sum of the resistance caused by the condition of the road (mud vs. gravel, etc.) and the resistance caused by the grade of the road.

To begin calculating cycle time, one would first determine the makeup of the haul road. The various road types and corresponding resistance percentages are shown in Table 3. Next, the haul distance must be separated into distinct segments, based upon changes in grade or type of road. When doing so, it is necessary to reduce the travel speed for acceleration/deceleration for a specified portion of the first and last segments of the haul road. The travel speed for those portions will be assumed to be one half that normally allowed for the given resistance. One would construct a resistance table at this time; an example is shown in Table 4 below. In the example the haul road is determined to be 2800 feet long of well-maintained earth throughout. The grade of the example haul road is shown in Table 5.

Table 3. Haul road types

Type	Rolling Resistance (lb/ton)	Equivalent Grade %
Smooth concrete	55	3
Good asphalt	70	4
Earth, well maintained	80	4
Earth, poorly maintained	110	6
Earth, moderate mud	180	9
Earth, heavy mud	240	12
Lose sand & gravel	200	10

Table 4. Resistance table example

Segment	Distance	Rolling Res.	Grade Res. (out)	Grad Res. (in)	Total Res. (out)	Total Res. (in)
Acc/Dec	200	4%	2%	-2%	6%	2%
1	800	4%	2%	-2%	6%	2%
2	1200	4%	5%	-5%	9%	-1%
3	400	4%	-3%	3%	1%	7%
Acc/Dec	200	4%	-3%	3%	1%	7%

Note: "Out" refers to travel from cut to fill (loaded), while "In" refers to travel from fill to cut (unloaded)

Table 5. Haul road example

Distance, in feet (traveling from cut to fill)	Grade resistance
1000	2%
1200	5%
600	-3%

Once the resistance table has been constructed, the travel speeds for given total resistances can be determined. For positive resistances, the performance chart for the chosen scraper is used. For negative resistances, the retarder chart is used if the chosen machine is equipped with a retarding device. If not, experience must be relied upon in determining the reduction in speed. A typical performance chart is shown in Figure 3, and a typical retarder chart is shown in Figure 4.

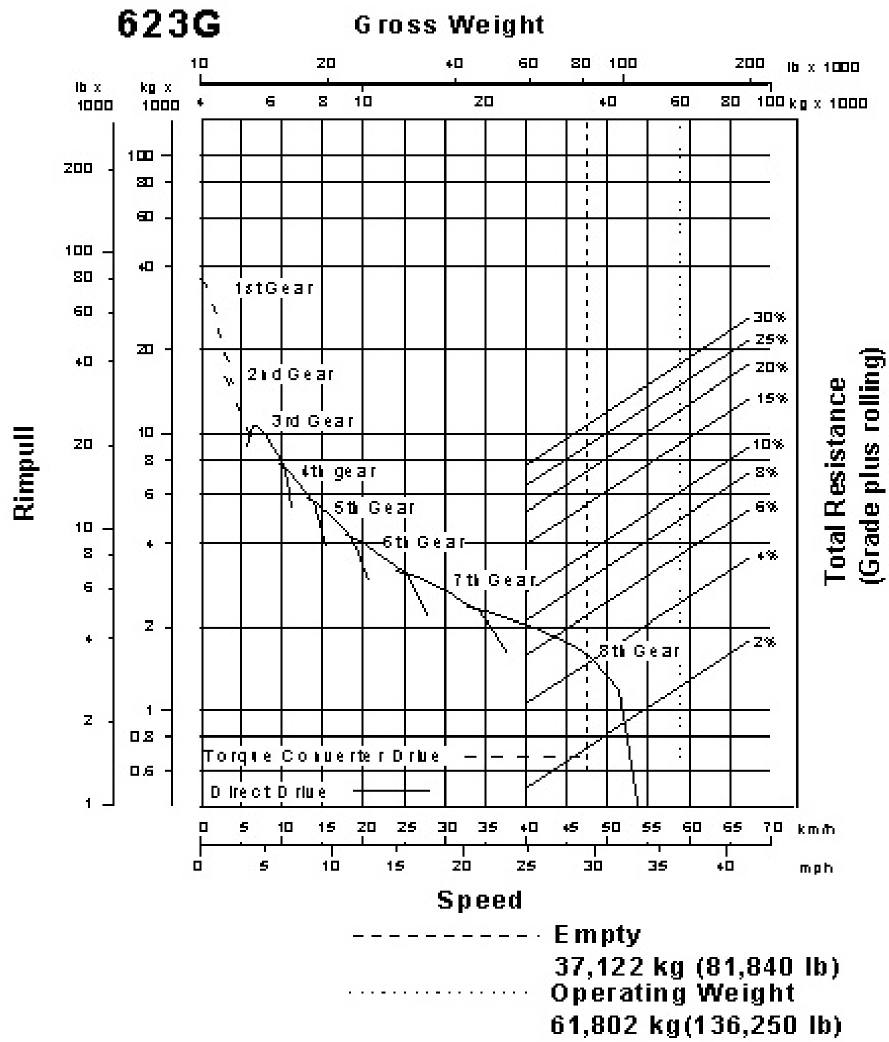


Fig. 3. Scraper performance chart

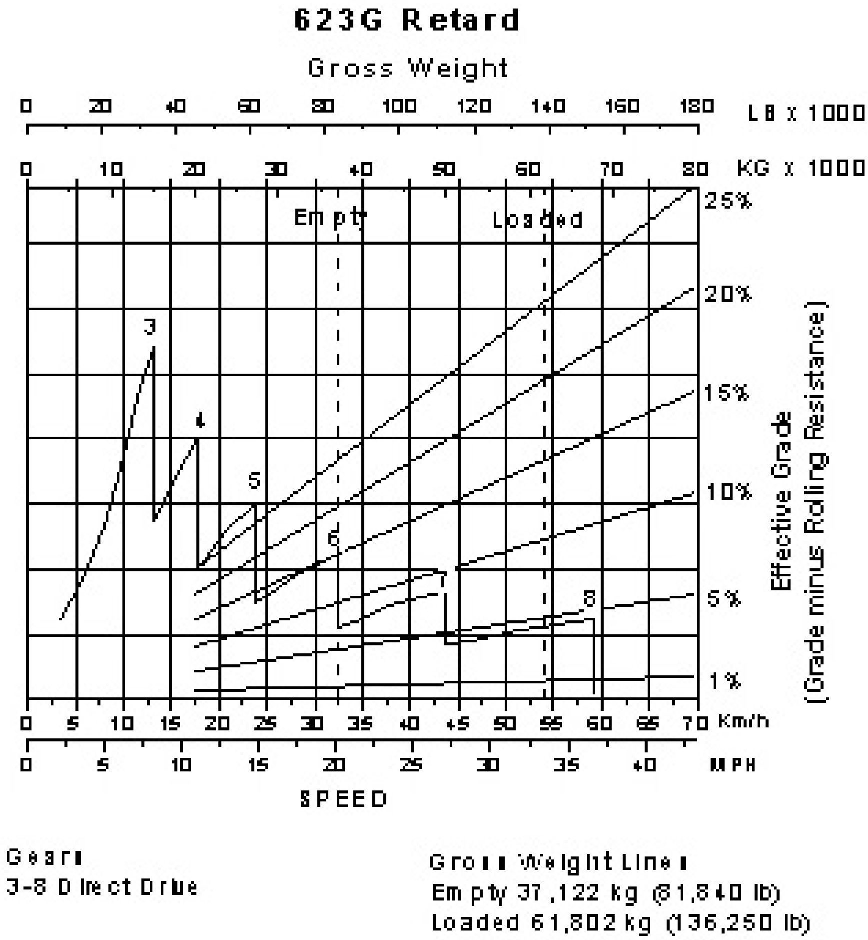


Fig. 4. Scraper retarder chart

In order to determine travel speeds using performance and retarder charts, the appropriate resistance percentage is found at the right side of the graph. Next, a diagonal line is followed to the vertical dashed line for the loaded or unloaded condition, depending upon whether the speed being looked up is for travel to or from the cut. When the intersection of diagonal and vertical line is determined, a horizontal line to the left intersects with the power curve of the scraper. Following a vertical line straight down, reading the travel speed off of the x axis can be read. These steps would be performed for every different resistance for the loaded and unloaded conditions. The resistance table would then be extended to include travel speeds. Table 6 shows the travel speeds (in miles per hour) determined in this manner for a Caterpillar 651E scraper.

Table 6. Travel speeds example

Segment	Distance	Rolling Res.	Total Res. (out)	Travel Speed (out)	Total Res. (in)	Travel Speed (in)
Acc/Dec	200	4%	6%	13 mph	2%	30 mph
1	800	4%	6%	13 mph	2%	30 mph
2	1200	4%	9%	8 mph	-1%	34 mph
3	400	4%	1%	33 mph	7%	17 mph
Acc/Dec	200	4%	1%	33 mph	7%	17 mph

Once the travel speeds have been determined, the travel times for each segment of haul road can be calculated from the following equation:

$$T_{Tr} = Segment\ Distance\ (ft) \div [88 * Speed\ (mph)] \qquad (3)$$

where T_{Tr} = travel time in minutes.

The travel times would be summed up as shown in Table 7

Table 7. Travel time example

Segment	Distance	Travel Speed (out)	Travel Time (out)	Travel Speed (in)	Travel Time (in)
Acc/Dec	200	6	.38	15	.15
1	800	13	.70	30	.30
2	1200	8	1.70	34	.40
3	400	33	.14	17	.27
Acc/Dec	200	16	.14	8	.28
TOTAL			3.06		1.41

Note: All travel times are given in minutes

Finally, the travel time would be added to the load time, turn times, and dump times to compute the cycle time:

$$T_S = T_{Tr} + T_L + T_{TF} + T_{TC} + T_D \quad (4)$$

The next step is the calculation of the pusher cycle time. One would use the following formula:

$$T_P = 1.4 * T_L + .25min \quad (5)$$

where T_P = pusher cycle time.

The fleet balance is determined at this stage. There will be an ideal number of scrapers to be used with one pusher. This number will most likely not be an integer. If the result of the calculation is rounded up, there will be some idle time among the scrapers. If the result is rounded down, the push tractor will be idle for some time. Both alternatives should be investigated. Fleet balance is calculated with the following formula:

$$N = T_S \div T_P \quad (6)$$

where N = ideal number of scrapers.

Production is calculated for the case in which scrapers control production (N is rounded down) and pushers control production (N is rounded up).

When scrapers control:

$$P = (E \div T_S) * N_1 * L \quad (7)$$

where P = production in BCY/hour; and N_1 = number of scrapers when scrapers control production.

When pushers control:

$$P = (E \div T_P) * L \quad (8)$$

The final step in estimation is the comparison of cost. For this example, only ownership and operator costs will be considered. In reality, multiple decisions must be made regarding rental versus leasing versus purchase. Calculations would proceed as follows:

When scrapers control:

$$Cost\ per\ BCY = (N_1 * C_S + C_P) \div P \quad (9)$$

where CS = scraper hourly cost; and CP = pusher hourly cost.

When pushers control:

$$Cost\ per\ BCY = (N_2 * C_S + C_P) \div P \qquad (10)$$

where N2 = number of scrapers when pushers control.

It can be seen that, if several different scrapers were considered, performing the required calculations could become tedious.

CHAPTER V

SYSTEM DESIGN

Performing the calculations necessary to estimate production with scrapers, as shown in the previous chapter, involved manually looking up data in charts, as well as construction of a rather involved table of quantities. In order to compare production rates between several different models, a great deal of time could be spent on the necessary calculations. The advisory system was designed to facilitate this process. Microsoft Excel was chosen both because it is designed to handle tabular data and because of its popularity. Th e advisory system is made up of seven separate worksheets: *User Interface*, *Calculations*, *Recommended*, *Soil Properties*, *Road Conditions*, *Scrapers*, and *Temp*.

User Interface

The *User Interface*, shown in Figure 5, is the worksheet designated to accept input from the user. The worksheet is write-protected in every cell, except for those in which data is needed from the user. These cells are colored yellow to identify them as data-entry cells. Drop-down menus are included in order to facilitate data entry. The *User Interface* is divided into six sections, or steps. In section 1, shown in Figure 6, the user may choose a single model from a list of all available scrapers. This section also contains three buttons, which trigger macro code. The first button, *Recommend Selectio*”, engages a macro which runs the estimation calculations for the conditions laid out in

---

See Appendix B.

sections 2 – 5 for every scraper in the database. This will be covered in more detail in a later section. The second button, *View Recommendation*", allows the user to toggle back and forth between the *User Interface* and *Recommended* worksheets. The third button, *Add New Scraper*, runs a macro which facilitates the addition of a new scraper to the database.

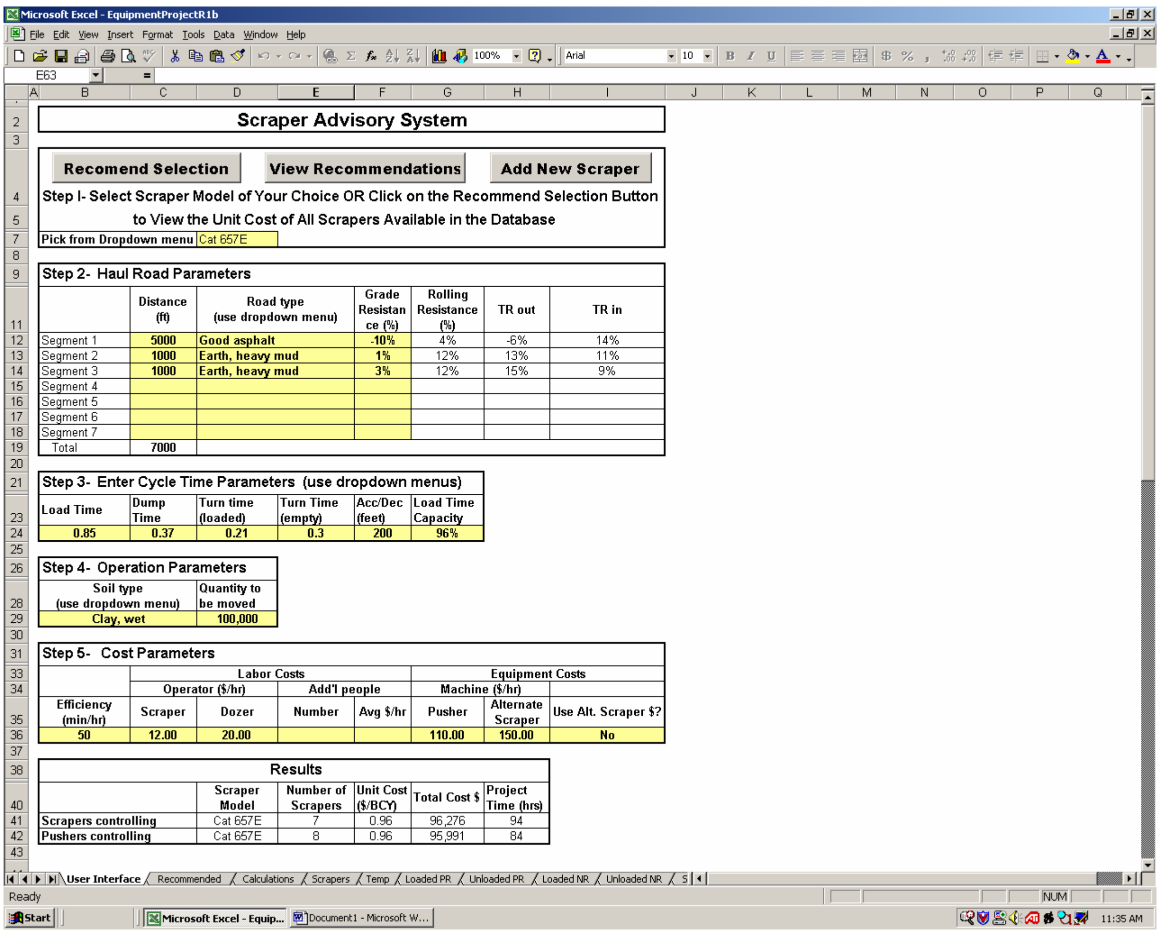


Fig. 5. *User Interface* worksheet

Fig. 6. *User Interface* section 1

Section 2, shown in Figure 7, requires the user to input data pertaining to the haul road. The advisory system allows for division of the haul road into a maximum of seven sections. This section is arranged in the form of the resistance table shown in Table 5. The user is prompted to input the distance of each segment, select the type of road from the drop-down menu, and input the grade resistance of that segment.

Step 2- Haul Road Parameters						
	Distance (ft)	Road type (use dropdown menu)	Grade Resistance (%)	Rolling Resistance (%)	TR out	TR in
Segment 1	500	Earth, heavy mud	-2%	12%	10%	14%
Segment 2	800	Earth, poorly maintained		6%	6%	6%
Segment 3	500	Earth, well maintained		4%	4%	4%
Segment 4	600	Earth, well maintained	5%	4%	9%	-1%
Segment 5	600	Earth, well maintained	1%	4%	5%	3%
Segment 6						
Segment 7						
Total	3000					

Fig. 7. *User Interface* section 2

The cycle time variables for a given project are entered in section 3, shown in Figure 8. Drop-down menus are used to solicit the load time (T_L), turn time at cut (T_{TC}), turn time at fill (T_{TF}), dump time (T_D), and percent loaded (%CAP). The user also enters the distance allowed for acceleration and deceleration at the fill and cut.

Step 3- Enter Cycle Time Parameters (use dropdown menus)					
Load Time	Dump Time	Turn time (loaded)	Turn Time (empty)	Acc/Dec (feet)	Load Time Capacity
0.85	0.37	0.21	0.3	200	96%

Fig. 8. *User Interface* section 3

Section 4 is the where the user is to input data specific to the project itself. The first cell allows the user to select from a list of earth types by using a drop-down menu. The next cell is for entry of the total quantity of material to be moved, in BCY. Section 4 is shown in Figure 9.

Step 4- Operation Parameters	
Soil type (use dropdown menu)	Quantity to be moved
Clay, wet	100,000

Fig. 9. *User Interface* section 4

Section 5, shown in Figure 10, allows entry of cost parameters for the project. The user selects the efficiency (E) to be used for estimating from a drop-down menu. The user also enters the hourly cost for the operator of both scrapers and push tractors. As an option, if there are additional personnel to be employed in the earthmoving project, the number of these people and the average of their hourly wages can be entered in this section. The user must also enter the hourly operational cost of the push tractor. Another option the use of a different hourly operational cost for a selected scraper from that cost listed in the database. The cell directly to the right of this alternate cost contains a dropdown Yes/No selection. It should be noted that this option should only be used when looking at cost data for a single scraper.

Step 5- Cost Parameters							
	Labor Costs				Equipment Costs		
	Operator ($/hr)		Add'l people		Machine ($/hr)		
Efficiency (min/hr)	Scraper	Dozer	Number	Avg $/hr	Pusher	Alternate Scraper	Use Alt. Scraper $?
50	12.00	20.00			110.00	150.00	No

Fig. 10. *User Interface* section 5

The final section is a display of the results for a selected scraper. In the first section, the user can select one specific scraper from the database for which to calculate production rate and cost. These results are shown in the last section for both the ‘scrapers-controlling’ condition and the ‘pusher-controlling’ condition. Shown are the scraper model, number of scrapers in a balanced fleet, cost per BCY, total project cost, and project time in hours. This section is shown in Figure 11.

Results					
	Scraper Model	Number of Scrapers	Unit Cost ($/BCY)	Total Cost $	Project Time (hrs)
Scrapers controlling	Cat 637G	4	0.70	69,791	121
Pushers controlling	Cat 637G	5	0.82	82,032	119

Fig. 11. *User Interface* results

Calculations

The top portion of the *Calculations* worksheet uses look-up functions to accumulate the data from the chosen scraper. Data entered by the user in the *User Interface* worksheet is also accumulated here. The remainder of the *Calculations* worksheet performs the estimation calculations as outlined in Chapter 4. The top portion of this worksheet is shown in Figure 12. It should be noted that the figures for the performance chart, while only visible in the picture up to 11%, actually go to 30%.

Operation Conditions											
General								**Site**			
Eff. Factor	**Scr Wage ($)**	**Push Wage**	**Push Cost ($)**	**BCY to Move**	**Acc/Dec**	**TT - Fill**	**TT - Cut**	**Soil**	**Bank Lb/CY**	**Swell**	
50	12.00	20.00	110.00	100000	200	0.21	0.3	Clay, wet	3000	74%	
Scraper			**Time**		**CY**		**Others**				
Make/Model	**Elevated?**	**Elev Factor**	**Load**	**Dump**	**Struck**	**Heaped**	**Capacity %**	**Payload**	**Max Sp**	**Hrly Cost**	
Cat 637G	No	1.1	0.85	0.37	21	31	96%	75000	33	100	
Performance Chart											
PR %, loaded											
0%	**1%**	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**	**11%**
33	33	33	32	28	22	17	16	13	12	11	10
PR%, unloaded											
0%	**1%**	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**	**11%**
34	34	33	32	31	29	27	25	22	20	17	16
Performance Retardation											
NR%, loaded											
-30%	**-29%**	**-28%**	**-27%**	**-26%**	**-25%**	**-24%**	**-23%**	**-22%**	**-21%**	**-20%**	**-19%**
3	3	3	3	7	7	7	10	10	10	10	10
NR%, unloaded											
-30%	**-29%**	**-28%**	**-27%**	**-26%**	**-25%**	**-24%**	**-23%**	**-22%**	**-21%**	**-20%**	**-19%**
10	10	10	10	10	10	10	10	10	10	10	10

Fig. 12. *Calculations* worksheet, top section

The first section of the *Calculations* worksheet calculates the value of L (actual load in BCY) using equations [2] and [2a]. Gross weight is calculated for both the heaped and struck capacities. The result of the former is compared to the maximum weight capacity of the scraper. The program selects the heaped capacity if the maximum weight is not exceeded. If it is exceeded, the struck capacity will be used. These steps are shown in Figure 13.

Calculations		
1. Calculate max CY (weight of soil vs max payload)		
Heaped CY * Capacity %	====>	29.76
Struck CY	====>	21
Heaped, adjusted for swell & elev factor	====>	24.22
Struck, adjusted for swell & elev factor	====>	17.09
Weight of full load, heaped	====>	72674
Weight of full load, struck	====>	51282
Max payload wt	====>	75000
If full load at heaped capacity > max payload wt, use struck BCY	====>	Heaped
Actual BCY	====>	24.22

Fig. 13. *Calculations* step 1

The next section of the *Calculations* worksheet computes the value of T_S (scraper cycle time). The haul road segments are referenced from the *User Interface* worksheet. An algorithm in the table determines which segment is the last (for example, even though up to seven segments could be entered, there might only be four), so that acceleration/deceleration distance can be deducted from it. A data validation code in the user interface limits entry of grade resistance so that total resistance falls within a range of 30% to -30%. Each scraper record in the database contains the travel speed for both unloaded and loaded conditions for every resistance within that range. Look-up functions in the table retrieve the appropriate travel speed for each segment so that the calculation shown in equation (3) may be performed. This section is illustrated in Figure 14.

The next section of the Calculations worksheet, shown in Figure 15, assembles all of the other variables which compose the cycle time and adds them to the travel time, thereby determining T_S (scraper cycle time) as per equation (4). Immediately following this section, T_P (pusher cycle time) is calculated using equation (5), shown in Figure 16. Directly beneath that, illustrated in Figure 17, N (fleet balance) is calculated using the formula in equation (6).

2. Calculate travel time									
	Total Res		Distance		Out		In		
Segment	Out	In	Out	In	Speed	Time	Speed	Time	
Accel	10%	3%	200	200	5	0.45	16	0.14	<=== Here, we look up the travel speed for the given
Decel	5%	14%	200	200	11	0.21	6	0.38	POSITIVE resistance percentage. Speed is calculated
1	10%	14%	300	300	11	0.31	13	0.26	like so: Time = Distance (in feet) / 88 * Speed
2	6%	6%	800	800	17	0.53	27	0.34	
3	4%	4%	500	500	28	0.2	31	0.18	
4	9%	-1%	600	600	12	0.57	0	0	
5	5%	3%	400	400	22	0.21	32	0.14	
0	0%	0%	0	0	33	0	34	0	
0	0%	0%	0	0	33	0	34	0	
						2.48		1.44	
Last Seg:	Segment 5		<====	This determines which segment is last, then enables the table to use that segment for decel calculations.					
	Total Res		Distance		Out		In		
Segment	Out	In	Out	In	Speed	Time	Speed	Time	
Accel	0%	0%	0	0	0	0	0	0	<=== Here, we do the same process
Decel	0%	0%	0	0	0	0	0	0	as above, but for negative resistance
1	0%	0%	0	0	0	0	0	0	percentages.
2	0%	0%	0	0	0	0	0	0	
3	0%	0%	0	0	0	0	0	0	
4	0%	-1%	0	600	0	0	34	0.2	
5	0%	0%	0	0	0	0	0	0	
0	0%	0%	0	0	0	0	0	0	
0	0%	0%	0	0	0	0	0	0	
						0		0.20	

Fig. 14. *Calculations* step 2

3. Calculate cycle time		
4.12	<====	sums up travel time calculated for favorable & unfavorable grades on in and out legs.
0.21	<====	turn time at fill, in minutes
0.3	<====	turn time at cut, in minutes
0.37	<====	dump time for this scraper
0.85	<====	load time for this scraper
5.850	<====	cycle time for this scraper

Fig. 15. *Calculations* step 3

4. Calculate pusher cycle time		
	$T_p = 1.4L_t + 0.25$	
	T_L = scraper load time	
1.44	<====	cycle time for pushers

Fig. 16. *Calculations* step 4

5. Calculate fleet balance		
	$N = T_s / T_p$	
T_s = scraper cycle time		
T_p = pusher cycle time		
3.3264		

Fig. 17. *Calculations* step 5

In the next section of the *Calculations* worksheet, the calculations described in equations (7), (8), (9), and (10) are performed side by side. The results are displayed in the *User Interface*. This is illustrated in Figure 18. Directly beneath this section, the same sets of results are placed in three lines, to allow for a user choice in the *Recommend Selection* macro. In the first line, the value of N resulting in the best BCY production rate is listed, along with the applicable results. In the second line, the results calculated for the situation where scrapers control are listed. In the last line, the results for the situation where pushers control are listed, as shown in Figure 19.

5	**6. Compare efficiencies**					
7						
3	Scraper Cost	130	<==== Allow user to alter the scraper cost			
9						
0			Scrapers Controlling		Pushers Controlling	
1	Production (BCY/hr)		1076.7		1193.9	
2	Cost (per hour)					
3	Operators		$ 56.0000		$ 68.0000	
4	Machines		$ 500.0000		$ 630.0000	
5	Add'l personnel		$ -		$ -	<=== Number of additional personnel
6	Total		$ 556.00		$ 698.00	* average wage rate
7	Cost (per BCY)		0.516		0.585	
8						
9	Project Time		92.87		83.76	
0	Project Cost		$ 51,638.16		$ 58,465.49	
1	Number of Scrapers		3		4	
2						

Fig. 18. *Calculations* step 6

7. Set up required numbers for Selection Recommendation Procedure	Scraper Model	Unit Cost ($/BCY)	Number of Scrapers	Controlling Machine	Total Cost $	Production (BCY / hr)	Project Time
Best BCY	Cat 637G	0.70	4	Scrapers	69,790.51	828	120.745
Scrapers Controlling	Cat 637G	0.70	4	Scrapers	69,790.51	828	120.745
Pushers Controlling	Cat 637G	0.82	5	Pushers	82,032.18	841	118.887

Fig. 19. Setup for *Recommend Selection* macro

Recommended

The *Recommended* worksheet, shown in Figure 20, is the location of the sorted results of the *Recommend Selection* macro. This program, launched via the *Recommend Selection* button in the User Interface, cycles each scraper in the database through the *Calculations* worksheet, and then copies one of the three lines shown in Figure 19 to the *Recommended* worksheet. Which line is copied depends upon whether the user chooses to use the best resulting BCY production, or specifies scrapers or pushers control. The *Return to User Interface* button in the upper right allows the user to toggle back and forth between the *User Interface* and *Recommended* worksheets.

Scraper Model	Unit Cost ($/BCY)	Number of Scrapers	Controlling Machine	Total Cost $	Production (BCY / hr)	Project Time (hrs)	Return to User Interface
Cat 657E	$ 0.48	3	Scrapers	$ 47,882.98	1161	86	
Cat 651E	$ 0.57	5	Scrapers	$ 57,287.40	1379	73	
Cat 637G	$ 0.58	4	Scrapers	$ 58,158.76	994	101	
Cat 631G	$ 0.63	5	Pushers	$ 63,406.52	1009	99	
Cat 627G	$ 0.76	3	Scrapers	$ 75,724.16	556	180	
Cat 621G	$ 0.84	4	Scrapers	$ 83,550.35	620	161	
Cat 623G	$ 0.84	4	Scrapers	$ 84,070.82	592	169	
Cat 611	$ 1.00	4	Scrapers	$ 99,645.10	440	228	
Cat 615C II	$ 1.10	4	Scrapers	$109,834.56	435	230	
Cat 613C II	$ 1.83	5	Scrapers	$183,123.46	295	339	

Fig. 20. *Recommended* worksheet

Soil Properties and Road Conditions

The *Soil Properties* worksheet, shown in Figure 21, contains the table of available types of earth to be moved. This table lists the weight per BCY and the swell factors for each type. The *Road Conditions* worksheet contains a table which lists the types of haul roads from which the user can choose. The table also lists the rolling resistances for these road types. Figure 22 illustrates the *Road Conditions* worksheet.

Earth & Rock properties				
Material	Bank Wt (lb/cy)	Loose Wt (lb/cy)	Percent Swell	Swell Factor
Clay, dry	2700	2000	35	0.74
Clay, wet	3000	2200	35	0.74
Earth, dry	2800	2240	25	0.8
Earth, wet	3200	2580	25	0.8
Earth & Gravel	3200	2600	20	0.83
Gravel, dry	2800	2490	12	0.89
Gravel, wet	3400	2980	14	0.88
Limestone	4400	2750	60	0.63
Rock, well blasted	4200	2640	60	0.63
Sand, dry	2600	2260	15	0.87
Sand, wet	2700	2360	15	0.87
Shale	3500	2480	40	0.71

Fig. 21. *Soil Properties* worksheet

Type	Rolling Resistance (lb/ton)	Equivalent Grade %
Smooth concrete	55	3%
Good asphalt	70	4%
Earth, well maintained	80	4%
Earth, poorly maintained	110	6%
Earth, moderate mud	180	9%
Earth, heavy mud	240	12%
Loose sand & gravel	200	10%

Fig. 22. *Road Conditions* worksheet

Scrapers

The *Scrapers* worksheet is the primary database. This worksheet contains a list of all available scrapers. Each record consists of the make, model, heaped and struck capacities, hourly operating costs, and maximum weight capacity for each scraper. There is also a Boolean field in each record to indicate whether or not the scraper is equipped with an elevating mechanism. Finally, each record contains the travel speeds for unloaded and loaded conditions for every total resistance within the range of 30% to -30%. This worksheet is sorted in alphabetical order according to make and model. Figure 23 shows a portion of the *Scrapers* worksheet.

									Loaded PR					
Item#	Make	Model	Elevated? (y/n)	Hourly Cost	CY - Struck	CY - Heaped	Payload (lb)	Max Speed (mph)	0%	1%	2%	3%	4%	5%
Cat 611	Caterpillar	611	No	65	10.5	15	36000	28	28	28	28	27	25	20
Cat 613C II	Caterpillar	613C II	Yes	70	8.9	11	26400	26	22	22	22	19	17	14
Cat 615C II	Caterpillar	615C II	Yes	75	12.8	17	40800	29	28	28	28	25	22	17
Cat 621G	Caterpillar	621G	No	85	14	20	48000	34	32	32	32	32	24	21
Cat 623G	Caterpillar	623G	Yes	80	18	23	55200	31	30	30	30	29	20	18
Cat 627G	Caterpillar	627G	No	85	14	20	48000	33	32	32	32	32	31	28
Cat 631G	Caterpillar	631G	No	90	21	31	75000	33	33	33	32	28	20	16
Cat 637G	Caterpillar	637G	No	100	21	31	75000	33	33	33	33	32	28	22
Cat 651E	Caterpillar	651E	No	120	32	44	104000	33	33	33	30	26	19	16
Cat 657E	Caterpillar	657E	No	130	32	44	104000	33	33	33	33	31	28	26
Items in database:		10												

Fig. 23. *Scrapers* worksheet

Temp

The seventh worksheet in the system is the *Temp* (temporary) worksheet. This sheet functions solely as a temporary storage area for the *Add New Scraper* macro. The next section will go into more detail on the macros. Figure 24 shows a portion of the *Temp* worksheet.

Make	Model	Elevated	Hrly Cost	CY Struc	CY Heaped	Max Payload	Max Speed		Scraper											
Caterpillar	639	Yes	88	88	88	88	88		Cat 639											
Positive Loaded																				
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Positive Unloaded																				
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Negative Loaded																				
-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	##	-14	-15	-16	-17	-18	-19	-20	-21
7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Negative Unloaded																				
-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	##	-14	-15	-16	-17	-18	-19	-20	-21
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Fig. 24. *Temp* worksheet

Macro Code

In addition to the seven worksheets, the system contains two sets of macro code. The first set is triggered by the *Add New Scraper* button in the *User Interface* worksheet. This code facilitates addition of a new scraper into the database. This macro uses six user forms to solicit data on all aspects of the scraper. These user forms are shown in Figures 25 through 30.

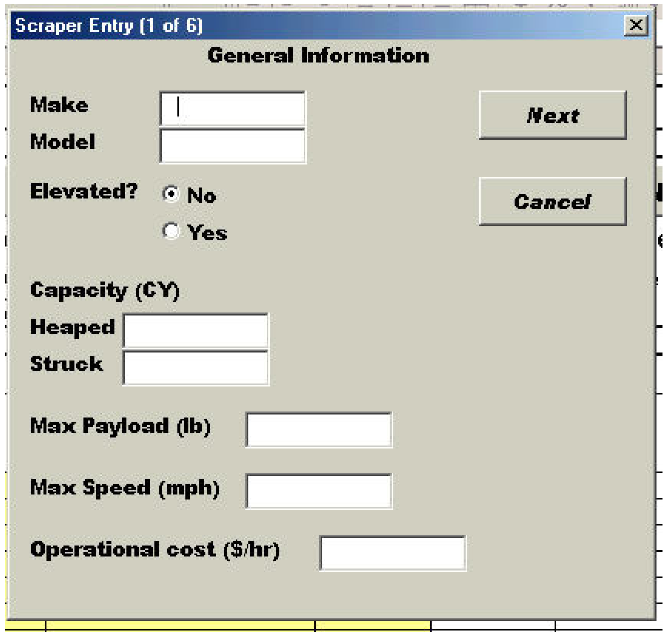


Fig. 25. *Add New Scraper* window 1 of 6

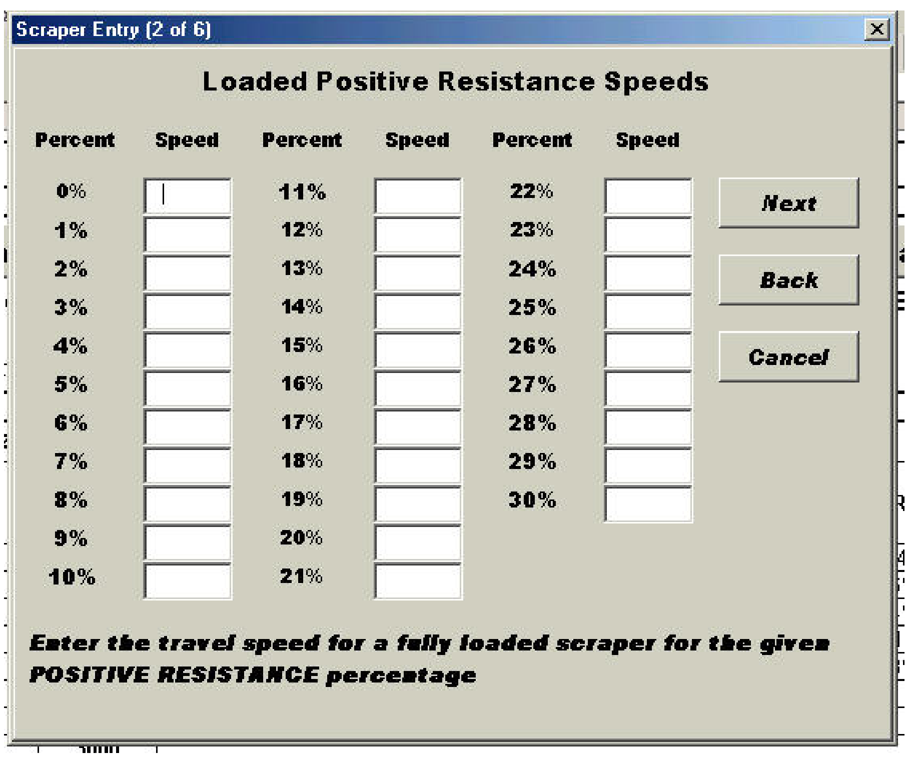


Fig. 26. *Add New Scraper* window 2 of 6

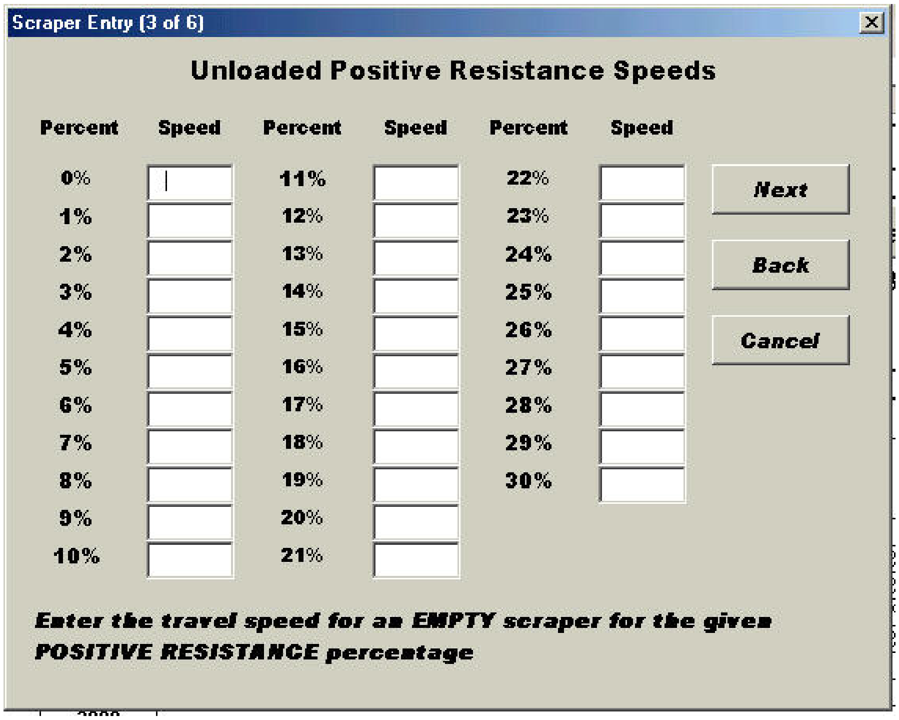


Fig. 27. *Add New Scraper* window 3 of 6

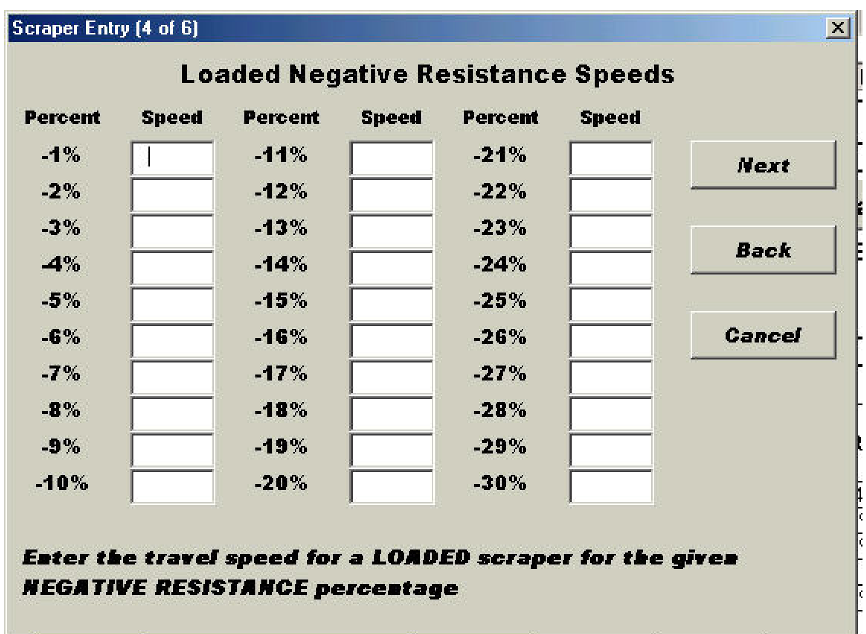


Fig. 28. *Add New Scraper* window 4 of 6

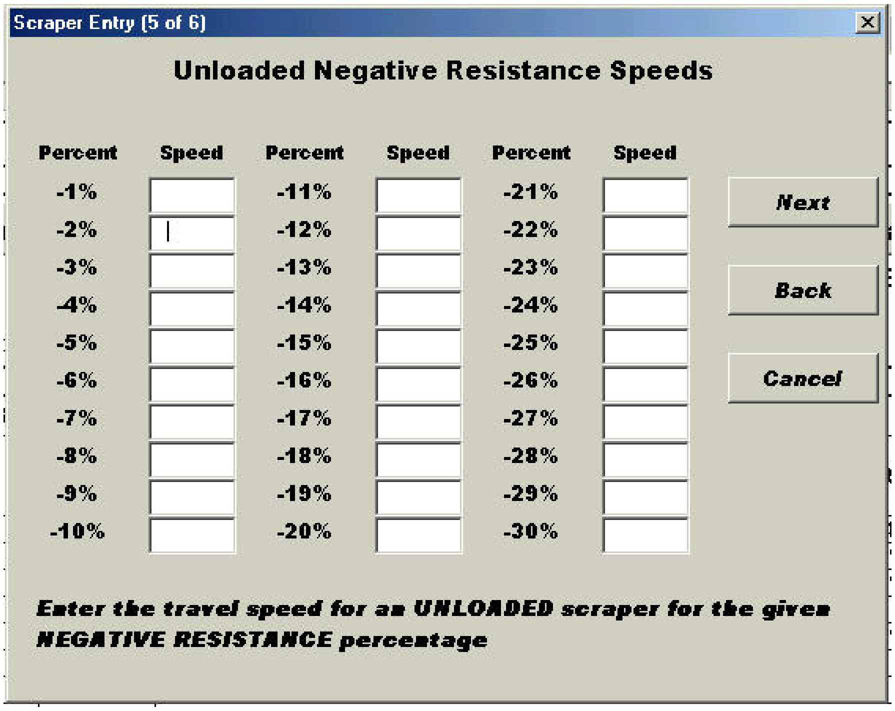


Fig. 29. *Add New Scraper* window 5 of 6

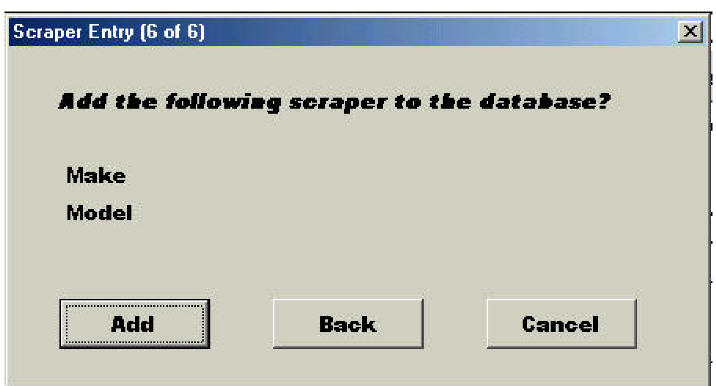


Fig. 30. *Add New Scraper* window 6 of 6

The second macro, activated by the *Recommend Selection* button, produces a list of all scrapers in the database, sorted in ascending order of efficiency. The user is given the choice of forcing the output to include only prices and production for scrapers controlling, or pushers controlling, or allowing the program to select the best option. The user also has the option of sorting the output by lowest price or best rate of production. The macro works by selecting the first scraper in the database and pasting that model number into the *User Interface*. The macro then copies the appropriate row from the bottom of the *Calculations* worksheet and pastes it into the *Recommended* worksheet. This process is performed for each scraper in the database. Finally, the macro sorts the *Recommended* worksheet in order of lowest price or best production rate, depending on the user's selection. Figures 31 and 32 show the selection windows.

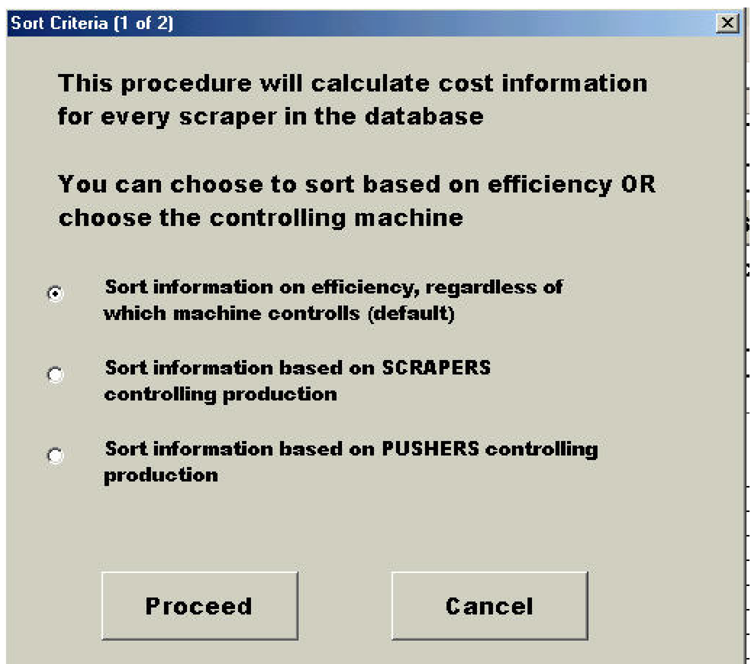


Fig. 31. *Recommend Selection* window 1 of 2

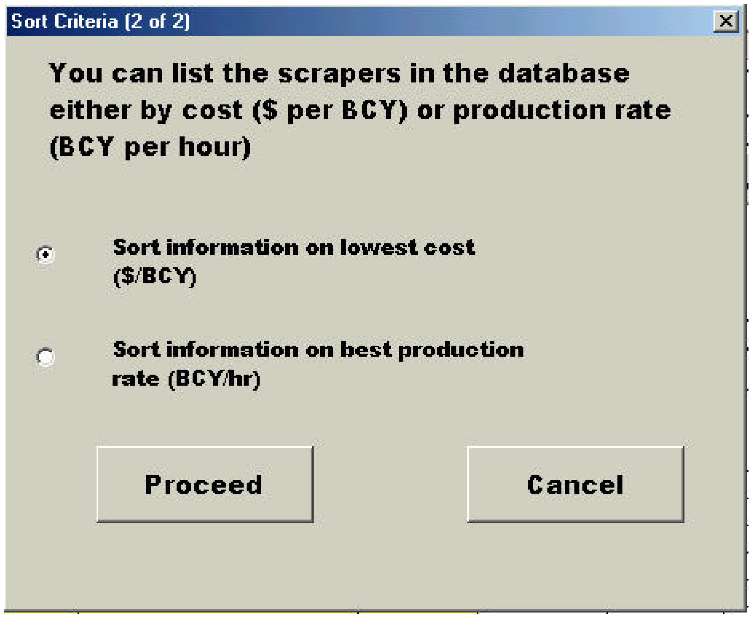


Fig. 32. *Recommend Selection* window 2 of 2

The next chapter illustrates a sample problem worked out step by step using equations (1) through (10). Snapshots of the input and output screens in the advisory system are shown, so that the results may be compared.

CHAPTER VI

SYSTEM RESULTS

In this chapter, an example problem is presented. The estimation calculations have been performed by hand and run through the system in order to compare the results. A list of recommendations will be generated for the sample data as well.

For the example, a haul road of 3000 feet will be assumed. The first 500 feet of the haul road consists of heavy mud with a -2% grade. The next 800 feet is poorly-maintained earth with a 0% grade. The next 500 feet is well-maintained earth with a 0% grade. The next 600 is be well-maintained earth with a 5% grade. The final 600 feet will be well-maintained earth with a 1% grade. The material to be moved is wet clay. The example is calculated for a Caterpillar 637G scraper. Table 8 shows the properties of this machine. Table 9 is a sample resistance table for the example haul road. Table 10 shows the properties of the earth to be moved.

Table 8. Scraper Properties

Scraper	Heaped Capacity (CY)	Struck Capacity (CY)	Maximum weight capacity (lb)	Hourly cost of operation ($)
CAT 637G	31	21	75000	$100.00

Table 9. Example haul road

Segment	Distance (ft)	Type	Rolling Resistance	Grade Res. (out)	Grade Res. (in)
1	500	Heavy Mud	12%	-2%	2%
2	800	Earth (poor maint.)	6%	0%	0%
3	500	Earth (well maint.)	4%	0%	0%
4	600	Earth (well maint.)	4%	5%	-5%
5	600	Earth (well maint.)	4%	1%	-1%
TOTAL	3000				

Table 10. Example material properties

Material	Bank wt (lb/CY)	Loose wt (lb/CY)	Percent swell	Swell factor
Clay, wet	3000	2200	35%	.74

The first step is to determine whether the heaped or struck capacity should be chosen, using equation (1). Once that decision has been made, the next step is to calculate L (BCY per load) using either equation (2) or equation (2a). In this example, the scraper, a CAT 637G, is not equipped with an elevating mechanism. It will also be assumed that, having observed the load growth curve, the scraper will be loaded to 96% capacity. The calculations are performed below. In this example, the maximum weight capacity of the scraper is 75,000 lb, therefore the heaped capacity can be used.

*Gross weight = 31 * .74 * .96 * 1.1 * 3000*

Gross weight = 72,674 lb

$L = 31 * 0.74 * 0.96 * 1.1$

$L = 24.22$ *BCY*

Next, the travel times for each segment of the haul road are calculated and summed. In this example, it will be assumed that the distance necessary for acceleration and deceleration is 200 feet. Table 11 shows these values. Table 12 shows the other cycle time variables assumed for this example. T_S (scraper cycle time) and T_P (pusher cycle time) can be calculated using equations (4) and (5).

$T_S = 2.48 + 1.64 + 0.21 + 0.37 + 0.3 + 0.85$

$T_S = 5.85$

$T_P = 1.4 * .85 + .25$

$T_P = 1.44$

Table 11. Example travel time

Segment	Dist.	TR (out)	TR (in)	Speed (mph) out	Speed (mph) in	Time (min) out	Time (min) in
Acc/Dec	200	10%	14%	5	6	.45	.38
1	300	10%	14%	11	13	.31	.26
2	800	6%	6%	17	27	.53	.34
3	500	4%	4%	28	31	.20	.18
4	600	9%	-1%	12	34	.57	.20
5	400	5%	3%	22	32	.21	.14
Acc/Dec	200	5%	3%	11	16	.21	.14
TOTAL						2.48	1.64

Table 12. Example cycle time parameters, in minutes

T_D (dump time)	T_{TF} (turn time at fill)	T_{TC} (turn time at cut)	T_L (load time)
.37	.21	.3	.85

Table 13. Example cost data, in dollars per hour

Scraper			Pusher		
Operator cost	Machine cost	Total cost	Operator cost	Machine cost	Total cost
12.00	100.00	112.00	20.00	110.00	130.00

Having calculated the cycle times, the fleet balance, N, can now be calculated using equation (6). In the highly likely event that N is not an integer, the production, P, when scrapers control and when pushers control will be calculated with equations (7) and (8). Cost parameters are shown in Table 13. An efficiency of 50 minutes worked per hour is used.

$N = 5.85 / 1.44$

$N = 4.06$

When scrapers control:

$P = (50 / 5.85) * 4 * 24.22$

$P = 828$ *BCY/hour*

Cost per BCY = (4 * \$112 + \$130) / 828

Cost per BCY = 70¢

When pushers control:

$P = (50/1.44) * 24.22$

$P = 841$ *BCY/hour*

Cost per BCY = (5 * 112 + 130) / 841

Cost per BCY = 82¢

The input and output of the advisory system is shown in Figures 34 and 35. The output for the *"Recommend Selection"* macro, using the example project parameters, is shown in Figure 33.

Recommend Selection | View Recommendations | Add New Scraper

Step I- Select Scraper Model of Your Choice OR Click on the Recommend Selection Button to View the Unit Cost of All Scrapers Available in the Database

Pick from Dropdown menu: Cat 637G

Step 2- Haul Road Parameters

	Distance (ft)	Road type (use dropdown menu)	Grade Resistance (%)	Rolling Resistance (%)	TR out	TR in
Segment 1	500	Earth, heavy mud	-2%	12%	10%	14%
Segment 2	800	Earth, poorly maintained		6%	6%	6%
Segment 3	500	Earth, well maintained		4%	4%	4%
Segment 4	600	Earth, well maintained	5%	4%	9%	-1%
Segment 5	600	Earth, well maintained	1%	4%	5%	3%
Segment 6						
Segment 7						
Total	3000					

Step 3- Enter Cycle Time Parameters (use dropdown menus)

Load Time	Dump Time	Turn time (loaded)	Turn Time (empty)	Acc/Dec (feet)	Load Time Capacity
0.85	0.37	0.21	0.3	200	96%

Step 4- Operation Parameters

Soil type (use dropdown menu)	Quantity to be moved
Clay, wet	100,000

Step 5- Cost Parameters

	Labor Costs				Equipment Costs		
	Operator ($/hr)		Add'l people		Machine ($/hr)		
Efficiency (min/hr)	Scraper	Dozer	Number	Avg $/hr	Pusher	Alternate Scraper	Use Alt. Scraper $?
50	12.00	20.00			110.00	150.00	No

Fig. 33. Example input

Results

	Scraper Model	Number of Scrapers	Unit Cost ($/BCY)	Total Cost $	Project Time (hrs)
Scrapers controlling	Cat 637G	4	0.70	69,791	121
Pushers controlling	Cat 637G	5	0.82	82,032	119

Fig. 34. Example results

In this example, there is a savings of 11¢ per BCY when scrapers control, despite the fact that the production rate is greater when pushers control. The final decision on how to properly balance the fleet would be up to the project manager or equivalent person. Though the system is not designed to make this decision, it is designed to allow flexibility in adjusting factors and speed in comparing results. Figure 35 shows the *Recommended* worksheet after running the *Recommend Selection* macro.

Scraper Model	Unit Cost ($/BCY)	Number of Scrapers	Controlling Machine	Total Cost $	Production (BCY / hr)	Project Time (hrs)
Cat 657E	$ 0.57	3	Scrapers	$ 57,459.58	968	103
Cat 651E	$ 0.69	5	Scrapers	$ 68,744.88	1149	87
Cat 637G	$ 0.70	4	Scrapers	$ 69,790.51	828	121
Cat 631G	$ 0.76	5	Pushers	$ 76,087.82	841	119
Cat 627G	$ 0.91	3	Scrapers	$ 90,868.99	463	216
Cat 621G	$ 1.00	4	Scrapers	$100,260.42	517	194
Cat 623G	$ 1.01	4	Scrapers	$100,884.99	494	203
Cat 611	$ 1.20	4	Scrapers	$119,574.12	366	273
Cat 615C II	$ 1.32	4	Scrapers	$131,801.47	363	276
Cat 613C II	$ 2.20	5	Scrapers	$219,748.16	246	407

Fig. 35. Example recommendations

CHAPTER VII

CONCLUSIONS

Results

This advisory system differs from the current trend in this area of research in that it was not designed to identify the single best piece of equipment for a given project. Rather, the idea behind this system was to automate an existing estimation technique in a way that allowed a great deal of flexibility in manipulation of project data. For example, if a company's internal data indicate that 45 minutes per hour was a more accurate efficiency, the selection could be easily changed using the drop-down menu in the *User Interface*. The same can be done for all factors which influence the production rate and cost.

The system was also designed to be user-friendly by building it in Microsoft Excel. Spreadsheet programs, Excel in particular, are in widespread use in the construction industry. This being the case, creating an advisory system that can be run on software and hardware already possessed by a company should make such a system more attractive.

The calculations generated by the system duplicate those generated by the hand calculations outlined in Chapter 4. This is the desired outcome, as it was not the method of estimation that was to be improved upon in the project, but rather the speed and flexibility of performing the required calculations. One of the most useful aspects of a spreadsheet application is the ability to change different variables and instantly see the effects of that change on the final result. By setting up the variables in the calculations necessary for scraper estimation in drop-down menus on one page of the application, users can rapidly run through several “what if” scenarios for the project at hand. The system could feasibly be used to verify such things as worker efficiency once a project was finished and actual cost data were available.

Suggestions for Further Research

While it is hoped that this system would prove to be immediately useful to an estimator working on an earthmoving project, there are some aspects of the application which could be expanded or otherwise improved upon. First, the *Soil Properties* and *Road Conditions* worksheets contain lists of different types of roads and soils, along with their applicable properties. These lists may not be exhaustive. It may, therefore, be useful to include macro code which would facilitate entry of new types of soils or roads in the same way as the *Add New Scraper* macro does for the *Scrapers* worksheet.

Another possible improvement might be a macro which allows the user to edit information in the *Scrapers*, *Soil Properties,* and *Road Conditions* worksheets. Currently, this could be done fairly easily by manually entering changes to each worksheet. If a macro program were employed, the worksheets could be protected, or even hidden to decrease the likelihood of data loss.

Third, it might be possible to expand the fleet balance calculations to allow for more than one pusher to be specified. This change could be implemented along with the ability to impose time constraints upon a project. For example, if a given quantity of material had to be moved in a certain time period, the program could increase the number of pushers and recalculate the fleet balance and production rate until the project time was sufficiently decreased.

Finally, the advisory system might be expanded to include different types of earthmoving equipment. For example, databases of backhoes, trucks, and dozers could be added. The *User Interface* could then be changed to allow the user to specify which type of equipment was preferred. The program could also generate production figures for dozers versus scrapers versus hoes/trucks so that side-by-side comparisons could be made. Macro code could be added which, like the current *Recommend Selection* macro, would calculate the production rate and cost for all sets of equipment in the database and sort them in order of best to worse, thereby providing the user with a master sorted list of earthmoving fleets.

REFERENCES

Alkass, S. & Harris, F. (1988). “Expert System for Earthmoving Equipment Selection in Road Construction.” *J. Constr. Eng. Manage.*, 114, 426-440.

Alkass, S. & Aronian, A. (1990). “Computer Aided Equipment Selection for Concrete Placing.” *Concrete International: Design and Construction*, 12, 38-45.

Amirkhanian, S. & Baker, N. (1992). “Expert System for Equipment Selection for Earth-moving Operation.” *J. Constr. Eng. Manage*. 118, 318-331.

Caterpillar Performance Handbook (30th ed.), (1999). Peoria, IL: Caterpillar Inc.

Christian, J. & Xie, T.X. (1996). “Improving Earthmoving Estimating by More Realistic Knowledge.” *Canadian J. of Civil Eng*., 23, 250-259.

Clemmens, J. & Willenbrock, J. (1978). “The SCRAPESIM Computer Simulation.” *ASCE J. of the Constr. Div.*, 104, 419-435.

Hanna, A. (1994). “SELECTCRANE: An Expert System for Optimum Crane Selection.” *Proceedings on the 1st Conference of Computing in Civil Eng.*, 1, 958-963.

Kuprenas, J. & Henkhaus, T. (2000). “SSPE – A Tool for Scraper Selection and Production.” *Computing in Civil and Building Eng.; Proceedings of the 8th International Conference*, 2, 980-987.

Peurifoy, R. L., & Schexnayder, C. J. (2002). *Construction Planning, Equipment, and Methods* (6th ed.). New York: McGraw-Hill.

Touran, A. (1990). “Expert System for Compactor Selection.” *J. Transportation Eng.*, 116, 338-348.

APPENDIX A

RECOMMEND SELECTION MACRO

```
Private Sub Proceed_Click()

'Clear the contents of the "Recommended" worksheet

Range("Recommend").ClearContents

Set r = Range("Scrapers")
Worksheets("Recommended").Activate
NumRows = Range("Recommend").Rows.Count
i = 3
For Each n In Range("Recommend")
   Range("Recommend").Rows(i).Delete
Next n

'Run scrapers through calaculations

For n = 1 To r.Rows.Count

   'Set the make/model of each scraper into the user interface

         Worksheets("User Interface").Range("d7").FormulaR1C1 =
         Range("Scrapers").Cells(n).Value

   'insert new row into the "Recommended" worksheet

   Worksheets("Recommended").Activate
   Rows("4:4").Select
   Selection.Insert Shift:=x1down

   'copy values from "Calculations" worksheet

   Worksheets("Calculations").Activate

   'We will select the criteria by which to select the BCY price

   If SortCriteria.SortMeth.Value = 1 Then
      Range("c117:i117").Select
   ElseIf SortCriteria.SortMeth.Value = 2 Then
      Range("c118:i118").Select
   Else
```

```
    Range("c119:i119").Select
  End If

  Selection.Copy
  Worksheets("Recommended").Activate
  Range("a4:i4").Select
  Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks
  _:=False, Transpose:=False
  Application.CutCopyMode = False

Next n

'Once all the scrapers have been run through calculations and
'and entered into the "Recommended" worksheet, that sheet is
'sorted by cost per BCY or by BCY/hr, depending upon the
'user selection

If SortType.Value = 1 Then
  Worksheets("Recommended").Activate
Range("Recommend").Sort Key1:=Range("b4"), Order1:=xlAscending,
Header:= _xlGuess, OrderCustom:=1, MatchCase:=False,
Orientation:=xlTopToBottom, _DataOption1:=xlSortNormal

  Worksheets("Recommended").Range("h4").Select

Else

  Worksheets("Recommended").Activate
Range("Recommend").Sort Key1:=Range("f4"), Order1:=xlDescending,
Header:= _xlGuess, OrderCustom:=1, MatchCase:=False,
Orientation:=xlTopToBottom, _DataOption1:=xlSortNormal

  Worksheets("Recommended").Range("h4").Select

End If

'Hide the userform

Unload SortCriteria
Unload Me

End Sub
```

APPENDIX B

EXCEL FILE

See attached Microsoft Excel file “AdvisorySystemR2.”

VITA

John Charles Mayfield earned a BBA in Accounting from Texas A&M University in 1994, and another BBA in Information Systems in 1996. He entered the Master of Science program in Construction Management in 2001, and finished work on the degree in May of 2004. His interests lie in the area of information systems and the possible applications of these in the construction industry. He has a particular interest in finding new uses for software packages such as Microsoft Excel, as these are already in widespread use and approachable by all. He can be reached by email at chuck1@tamu.edu. His mailing address is 2009 Wayside, Bryan, TX 77802.