DEVELOPING A COAL TRANSPORTATION COST ESTIMATION MODEL FOR TURKISH COAL ENTERPRISES

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

EBRU DEMİR

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
MINING ENGINEERING

FEBRUARY 2009

Approval of the thesis:

DEVELOPING A COAL TRANSPORTATION COST ESTIMATION MODEL FOR TURKISH COAL ENTERPRISES

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ABSTRACT

DEVELOPING A COAL TRANSPORTATION COST ESTIMATION MODEL FOR TURKISH COAL ENTERPRISES

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February 2009, 103 Pages

Transportation cost is an important item in total operating cost of an open pit mining operations. In some projects, the transportation cost may reach to 60 % of total operating cost. Turkish Coal Enterprises (TKİ) delivers the demanded coal to all cities of Turkey within the context of Prime Ministry Social Solidarity and Aid Fund. The project duration, demanded coal amount whether the coal is needed as packed or unpacked form are determined by local governors. In this study, a model is developed through software, called NAKMAL for the estimation of TKİ's coal transportation cost. Transportation cost model is coded using Visual Studio.NET 2005. This model is designed in modular structure and composed of 19 modules. Excavation and transportation in a mine is an important part of the model. Model considers all the highway, railway and transportation by ship alternatives, as well as the packing operation. This model is being used in evaluation of bids by the decision of TKİ's board of executive committee.

Keywords**:** Transportation cost model, Visual Studio.NET, NAKMAL, software.

ÖZ

TÜRKİYE KÖMÜR İŞLETMELERİNİN KÖMÜR NAKLİYESİ İÇİN BİR MALİYET TAHMİN MODELİ GELİŞTİRİLMESİ

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Şubat 2009, 103 Sayfa

Açık ocak maden işletmelerinde, işletme maliyetinin önemli bir kısmını nakliye maliyeti oluşturmaktadır. Bu oran bir çok çalışmada işletme maliyetinin % 60'ına kadar ulaşabilmektedir. Türkiye Kömür İşletmeleri (TKİ) Kurumu Başbakanlık Sosyal Dayanışma ve Yardımlaşma Fonu kapsamında, Türkiye'nin tüm illerine taleplerine göre kömür sevk etmektedir. Proje süresi, talep edilen kömür miktarı ve kömüre hangi halde -dökme ya da torbalı- ihtiyaç duyulduğu bilgisi yerel yönetim tarafından tespit edilmektedir. Bu çalışmada TKİ kömür nakliye maliyet hesabına etki eden bütün bileşenler, NAKMAL isimli bir bilgisayar yazılımı kullanılarak modellenmiş ve bir yaklaşık nakliye maliyet hesap modeli oluşturulmuştur. Modelin kodlanmasında Visual Studio.NET 2005 platformu kullanılmıştır. Yazılım modüller halinde tasarlanmış olup 19 modülden oluşmaktadır. Ocak içi kazı ve nakliye modelin önemli birer elemanıdır. Ayrıca karayolu, demiryolu ve denizyolu nakliye seçenekleri ve torbalama işleri de modellenmiştir. Bu model, TKİ yönetim kurulu kararı ile kömür nakliye ihalelerinde, gelen tekliflerin değerlendirilmesinde kullanılmaktadır.

Anahtar Kelimeler: Nakliye maliyet modeli, Visual Studio.NET, NAKMAL, yazılım.

To My Son and Family

ACKNOWLEDGEMENTS

I wish to express my deepest gratitude to my supervisor Prof. Dr. Celal Karpuz for his guidance, advice, criticism, encouragement and insight throughout the research.

I would also like to express special thanks to other members of NAKMAL project team, Assoc. Prof. Dr. Şebnem Düzgün and Dr. Nuray Demirel.

I acknowledge to help provided by the General Directorate of Turkish Coal Enterprises, especially Mr. Mustafa Özdingiş and his staff.

Special thanks to Mr. Haydar Rıdvan Temel for his help.

Special thanks to Mr. Mustafa Erkayaoğlu for his help.

Thanks to research assistants Mr. Mustafa Kemal Emil, Mr. Ömer Erdem and Mr. Recep Kaya for their motivation.

I am also deeply indebted to my son, Meriç Cantekin, to my mother and father and to my sisters İlknur Demir, Zekiye Demir and Işılay Demir.

Thanks to Sinan Kapoğlu, Devrim Piroğlu, Levent Güneş and Nezir for their motivation.

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LIST OF SYMBOLS

A	Angle of swing correction factor
AT	Actual working duration
$A_s(t)$	Number of annual passengers
C_d	Bucket capacity of loading equipment
$C_{ex}(t)$	Time dependent external cost
$C_f(t)$	Time dependent lost of cost
$C_k(t)$	Time dependent annual capital
CL_P	Cost of lunch for labors working in the packing plant
CL_R	Food cost in railway transportation
$C_m(t)$	Time dependent operational maintenance cost
Cn_e	Fuel consumption for the loading equipment
Cn_l	Consumption rate for l^{th} type road
Cn_P	Electricity consumption rate in packing plant
Cn_T	Fuel consumption rate of the truck
Cp_P	Capacity of the packing plant
Cp_T	Capacity of the trucks
Cp_W	Wagon capacity of the train
C_R	Cover cloth cost
d	Density of the coal
D	Depth of cut correction factor
DC_B	Depreciation cost of balancing machine
DC_e	Depreciation cost of loading equipment
DC_F	Depreciation cost of forklift
DC_P	Depreciation cost of packing plant
DC_T	Depreciation cost of truck
D_l	Distance travelled for l^{th} type road
dr	Discount rate

DT_B Depreciation time of balancing machine

DT_e Depreciation time of the loading equipment

DT_F Depreciation time of forklift

DT_P Depreciation time for packing plant

DT_T Depreciation time of trucks

E Efficiency factor of loading equipment

EC_e Employer cost in excavation or loading

E_P Electricity cost in packing plant

E_T Efficiency factor of the truck

F Fill factor of loading equipment

FC_D Fuel cost of trucks if both mine road segments and highway segments are present

FC_e Fuel cost of the loading equipment

FC_T Fuel cost of the truck

F_T Fill factor of the truck

GR Grade resistance

H Number of hours in a shift

hh Cost of unit cap hat

i index for labor type

I_B Investment cost of the balancing machine

IC_e Interest cost of the loading equipment

IC_P Interest cost for the packing plant

IC_T Interest cost of the truck

I_e Investment cost of the loading equipment

I_F Investment cost of forklift

I_P Investment cost of packing plant

I_T Investment cost of the truck

j Employer type (Mine manager, engineer, formen, officers)

k Types of plant labors index

l Road type index (highway, mine road)

LC_e Labor cost for lading equipment

LC_R Labor cost

LC_T Labor cost for the transportation

MF Match factor

n Economic lifetime of a vehicle

n_c Number of total cycle for trucks

n_c Number of cycles for all trucks

n_d Number of truck drivers

n_e Number of excavators

n_e Number of loading equipments

n_j Number of j^{th} type employers

n_k Number of k^{th} type labors

n_l Number of loaders

n_P Number of labors working in the plant

n_R Number of labors working to load/unload the wagons in a shift

n_s Number of shifts in a day

n_T Number of trucks

nt_l Number of tires of the loader

nt_T Number of tires of the truck

pc Cost of unit protective clothes

PC_P Protective equipment cost

P_d Amount of coal demanded

PD Number of working days for the loading equipment

pm Cost of unit dust protective

P_p Amount of coal produced

pp Powder coal coefficient which is equal to 0.15.

Pr_e Productivity of the loading equipment

Pr_T Productivity of the truck

ps Cost of unit protective shoes

Q Hourly production in place

rr	Cover cloth cost coefficient
RR	Rolling resistance
S	Swell factor
sc	Salvage value coefficient
S_d	Salary of truck driver
S_i	Salary of i^{th} type labor
S_j	Salary of j^{th} type labor
S_k	Salary of k^{th} type labor
SN	Swing number
TC_D	Tire cost of trucks if both mine road segments and highway segments are present
TC_l	Tire cost of loaders
TC_P	Labor training cost for packing plant
TC_R	Transportation cost by wagons
TC_S	Cost of transportation by ship
TC_T	Tire cost of trucks
t_d	Maneuvering and dumping time
t_f	Returning back time for loading
t_h	Transport time while truck is loaded
t_l	Loading time
TL_l	Tire life for l^{th} type road
t_p	Maneuvering time before loading
TP_l	Price of the loader tire
TP_T	Price of the truck tire
TR	Total resistance
t_s	Cycle time of loading equipment
t_T	Cycle time of the truck
uc_d	Unit cost of unloading
UCF	Unit cost of fuel
UCL	Food cost per labor

uc_l Unit cost of loading

UCT Unit cost of railway transportation

uc_t Unit cost of transportation by

UEP Unit cost of electricity

UPB Price of a cover clothe

UPT Unit cost of a truck tire

U_T Equivalent and uniform total cargo or passenger cost

UTC Yearly training cost per labor

Wd Number of working days for the loading equipment

Wd_e Number of working days for excavator/loader

Wd_L Number of working days for loader

Wd_P Number of plant working days

Wd_T Number of working days for the truck

Wh_e Number of total working hours for loading equipments

Wh_l Number of working hours through l^{th} road type

Wh_P Number of working hours of plant to meet requirement

Wh_T Number of total working hours for all trucks

ww Daily wages of a labor

x Distance of the truck cycle

$Y_s(t)$ Number of annual cargoes

CHAPTER 1

INTRODUCTION

In mining activities, material handling and transportation is a significant component of operating cost. There are a considerable number of researches completed about excavator/loader truck productivity for surface mines to decrease material handling cost. It is stated by Naoum and Haidar (2000) that optimality and optimal solutions are important for the industries where even a small increase in efficiency can turn to huge savings. This study provides information concerning the operating cost of material handling in surface coal mines and transportation in optimal basis.

Optimal cost of material handling can be achieved by proper equipment selection. It is stated by Burt *et al*. (2005) that current industrial practice relies on solutions that do not select from the entire set of available truck and loader types, but rather select from small handpicked subsets. Homogenous fleet assumption is a common assumption in equipment selection problems. Another common restriction in equipment selection is maximum passes from loader to truck restriction. Truck-loader productivity is another factor to achieve an optimal solution. Match factor is an indicator of suitability of loader fleet to truck fleet. The point is stressed by Burt and Caccetta (2007) that match factor have been used in mining and construction industries for many decades as an indicator of productivity performance. It is stated by Naoum and Haidar (2000) that equipment selection problem is a complex problem and many features, restrictions and criteria should be considered.

It is stated by Yıldız (1995) that vehicle operating cost studies are first received attention in North America after the First World War. There are considerable amount of study about vehicle operating cost since First World War. It is stated by Şahin *et al*. (2009) that transportation cost is a vital importance in an economy of a

nation, a region, or a city and low cost give an advantage to a business concern to be competitive. It is stressed that, calculating total transportation costs accurately and trying to minimize them is a necessity. It is emphasized by Litman (1999) that transportation decisions are affected by the distribution of costs and the consumers are most affected by internal variable costs. There are considerable amount of study in the literature to optimize the transportation networks and lower the transportation costs.

The total cost can be expressed as summation of capital cost and operating cost or can also be expressed as the sum of fixed and variable cost items. The operating cost items can be listed as depreciation cost, interest cost, fuel cost, oil cost, spare parts cost, repair and maintenance cost, labor cost and tire cost. Fuel cost item is an important one among the operating cost items. Vehicle operating cost is affected by geometrical and physical properties of road, vehicle type and mechanical properties of the vehicle. Road features are important in defining the rolling and grade resistance so the cycle time and the fuel consumption rate of the vehicles.

1.1 Study Objectives

TKİ delivers coal to all cities of Turkey in the context of a Prime Ministry Social Solidarity and Aid Fund every year. The demanded coal amount, project duration and whether the coal is needed as packed or unpacked form is determined by the local authority and TKİ is informed about the details of the project. TKİ is responsible from delivering the needed amount of coal demanded by the local authorities hence controls the work of the contractors.

The goal of this study is to compute the total transportation cost of coal delivered from a mine to a destination point for different transportation alternatives, including material handling, stockpiling cost and packing cost. In this study, a model is

developed, called NAKMAL, for the estimation of TKİ's total coal transportation cost.

NAKMAL is coded in Visual Studio .NET 2005 and is designed in modular structure. The coal transportation alternatives presented in Chapter 3 from a mine to a destination point are divided into subsystems and total 19 modules are designed in the software to compute the cost of these subsystems.

1.2 Problem Statement

TKİ delivers coal to all cities of Turkey in the context of a Prime Ministry Social Solidarity and Aid Fund every year. The demanded coal amount, project duration whether the coal is needed as packed or unpacked form is determined by the local authorities and TKİ is informed about the details of the project. TKİ is responsible from delivering the needed amount of coal defined by the local authorities to the destination points and call for the tenders. An approximate coal transportation cost value is needed to evaluate the proposals prepared by the contractors.

1.3 Objective and Scope of the Study

The goal of this study is to compute the total transportation cost of coal delivered from a mine to a destination point for different transportation alternatives, including material handling, stockpiling cost and packing cost. In this study, a model is developed through the software, called NAKMAL for the estimation of TKİ's total coal transportation cost.

1.4 Research Methodology

This study is completed in two stages. In the first stage, equipment fleets is decided and a database is prepared. In the second stage, a cost estimation model is developed for delivering of coal from a mine to a destination point.

Data collection for the equipments in the fleet is utilized through making contact with the producer companies and by catalogues. The equipment data gathered from different companies are used to specify the features of equipment. Packing plants available for TKİ's use and their specifications are achieved from TKİ.

In modeling the transportation cost, the variables are decided by examining mine road conditions of TKİ and highway road conditions of Turkey. Roads are classified according to their rolling resistances. Fuel consumptions of vehicles in different road conditions are determined according to experimental data of TKİ. For the estimation of the vehicle speeds through mine road segments, regression equations are fitted. In modeling the coal material handling cost, the cost coefficients are determined according to experimental data of TKİ.

The database is created in Microsoft Access and the model is coded in Microsoft Visual Studio.NET 2005.

1.5 Outline of the Thesis

This thesis is composed of seven chapters. In the first chapter, general information is supplied about the thesis and problem. In the second chapter, a literature survey is given. The literature survey is related with coal material handling cost, equipment selection in mining and transportation cost. In the third chapter, the coal demand amounts of the cities and coal transportation alternatives are explained. In the fourth chapter, the fundamentals of the model are explained. In the fifth chapter, the

modules of the software are explained. In the sixth chapter model validation is verified and in the last chapter, related conclusions and recommendations are denoted.

CHAPTER 2

COST MODELING

2.1 Coal Material Handling and Equipment Selection

It is stated by Alarie and Gamache (2002) that one of the most important aspects of open-pit mine operation is material transportation and it represents 50 % of operating cost. Some authors estimate that it can reach 60% of operating cost for some mines.

Equipment selection and cost analyses in an open pit mine are studied by Paşamehmetoğlu *et al*. (1988). The model developed in this study is used by TKİ to prepare and evaluate contractual agreements. Equipment fleet selection is utilized to minimize unit-stripping cost in the study. Classical excavator production formula is used to find the hourly production of an excavator. In finding the production of trucks, calculation of cycle time of the trucks are needed and the factors affecting cycle time are described as road condition, rolling resistance, grade resistance, road profiles, truck travel performance curves, speed limiting factors on the road, cycle time of the loader and number of passes required for a loader to fill the truck. A maximum achievable speed for a truck is represented by suitable equations after regression curves is fitted for the truck travel performance curve in the study. Cost of equipment is computed by summing up capital and operating cost of equipment in the equipment fleet. Depreciation cost, insurances and taxes are regarded as capital cost items whereas fuel and oil, maintenance and repair and supplies and labor costs are regarded as operating cost items in the study. It is stated Paşamehmetoğlu *et al*. (1988) that fuel cost is one of the important operating cost items and regression equations are fitted to estimate fuel consumption rate of the

machines in the study. Unit stripping costs of equipment fleets are compared and a decision is made to select the optimum equipment fleet. Two hypothetical cases from two different formations in one of the mining sites of TKİ are selected to demonstrate the use of model and to compare the cost of optimum equipment fleet with the cost of equipment fleet selected by the contractor. It is reported that loading and hauling costs in contractor's cases are very high compared to that of the optimum equipment fleet. Hence, millions of Turkish Liras and time is saved since the development and implementation of the model.

Match factor is an important indicator in equipment selection. It is stated by Burt and Cacetta (2007) that the formula determining the number of trucks, M_b to balance shovel output is published by Douglas (1964) and given in equations 2.1, 2.2 and 2.3. It is noted that Douglas ratio is restricted to one loader.

$$\text{Loader Productivity} = \frac{\text{Loader Capacity} * \text{Loader Efficiency}}{\text{Loader Cycle Time}} \tag{2.1}$$

$$\text{Truck Productivity} = \frac{\text{Truck Capacity} * \text{Number of Trucks}}{\text{Truck Cycle Time}} \tag{2.2}$$

$$M_b = \frac{\text{Loader Productivity}}{\text{Truck Productivity}} \tag{2.3}$$

It is stated by Burt and Cacetta (2007) that Morgan and Peterson (1968) presents a simpler version of the match factor, MF, formula as given in equation 2.4,

$$MF = \frac{\text{Number of Trucks} * \text{Loader Cycle Time}}{\text{Number of Loaders} * \text{Truck Cycle Time}} \tag{2.4}$$

According to Burt and Cacetta (2007), the waiting times are not included to Peterson's formula. Application of match factor as a productivity indicator is

focused in the study, queues and idle times are included in cycle times while studying with heterogonous fleets. They developed the below formula to calculate the match factor of heterogeneous fleets:

$$MF = \frac{(\text{Number of Trucks}) * \sum_j[(\text{Number of Trucks}) * \text{lcm}(\text{unique loading times})_j]}{(\text{Loaders}_j * \sum_j \frac{\text{lcm}(\text{unique loading times}_j)}{\text{unique loading time}_{i,j}}) * \sum_i[\text{trucks}_i * \text{Truck Cycle Time}_i]} \quad (2.5)$$

where,

Number of trucks: The total number of trucks in the fleet

$Trucks_i$: The number of trucks of type i in the fleet

$Loaders_j$: The number of loaders of type j in the fleet

Unique loading $time_j$: The cycle time of the loader j when working with one truck type i

Truck cycle $time_i$ The cycle time of truck type i

Truck cycle time: The average cycle time for all trucks in the current period

lcm(unique loading times): The least common multiple of the unique loading times for all j.

Unique loading $time_j$: The cycle time of the loader j when working with one truck type.

Unique loading $time_{i,j}$: The cycle time of the loader j when working with a truck type i

It is concluded by Burt and Cacetta (2007) that project managers are less restricted in their choice of equipment and can select mixed fleets and minimize material handling expense.

The main specific features related to the equipment selection problem are stated by Naoum and Haidar (2000) as:

- The equipment selection process involves the assessment of the site parameters, soil characteristics and operating conditions.
- The equipment selection process implies choosing the type, make, size and the number of units required to meet a selected life and production rate.
- Cost estimation is an intrinsic component of the complete process. In fact, the essential objective of the research is to define the right type, number and size of equipments that produce the minimum cost.

The software XSOME, in the study of Naoum and Haidar (2000) is progressed to assist the decision maker by producing an intelligent support system, in the form of a hybrid knowledge based on genetic algorithms to select the type, make number and operating life of the excavating and haulage equipments that can minimize the total cost of the overburden removal operation in an opencast mine.

Equipment selection problem is studied by Haidar *et al.* (1999). The point is stressed that optimum equipment selection for a mine is complex and it can be broken down into a series of relatively well defined variables directly related to the general mine conditions. It is stated in the study that optimization techniques has been in recession to allow the new developed artificial techniques like genetic algorithms. Cost of excavating and haulage of the overburden in opencast mines is calculated for four case studies. Equipment selection problem is solved through genetic algorithms and stripping and hauling cost is calculated by the software XSOME and it is tested for four case studies in this study. It is concluded in the study that application of the genetic algorithms in equipment selection in opencast mining is a well-structured method forcing the user to take into consideration different aspects of the problem.

2.2 Transportation Cost Modeling

Sahin *et al.* (2007) presents transportation cost analysis based on the economic analyses of the alternative modes of cargo or passenger transportation. The total transportation cost for a cargo or passengers is divided into its main components which are capital, fuel, lubricants and operational and maintenance costs. The levelized cost analyses method, which is presented by Sahin *et al.* (2005) and Aybers and Sahin (1995), is utilized to determine the transportation cost in the study of Sahin *et al* .(2007). According to the method, the unit cost of capital, on a reference date, have been formulated as follows:

$$\mathbf{U_T} = \frac{\sum_{i=1}^{n}[\mathbf{C_k(t)} + \mathbf{C_f(t)} + \mathbf{C_m(t)} + \mathbf{C_{ex}(t)}] * (\mathbf{1}+\mathbf{r})^{-t}}{\sum_{i=1}^{n}[\mathbf{Y_{s(t)}} + \boldsymbol{\alpha}\mathbf{A_s(t)}] * (\mathbf{1}+\mathbf{r})^{-t}} \tag{2.6}$$

Where; U_T is the equivalent and uniform total cargo or passenger cost per unit during the economic lifetime of the vehicle, $C_k(t)$ is the time dependent annual capital, $C_f(t)$ is the time dependent cost of fuel and lubricants, $C_m(t)$ is the time dependent operational and maintenance costs and $C_{ex}(t)$ is the time dependent external cost, r is the discount ratio, n is the economic lifetime of the vehicle, $Y_s(t)$ and $A_s(t)$ are the number of annual cargoes and passengers and α is an equivalent coefficient representing the ratio of the unit cost of car transportation to that of passenger transportation. The cost analysis is conducted and costs are compared by Sahin *et al*. (2009) for different modes of transportation. The change in the total transportation cost per cargo based on the route length and fullness ratio for 20 tonne capacity truck is as given in Figure 2.1.

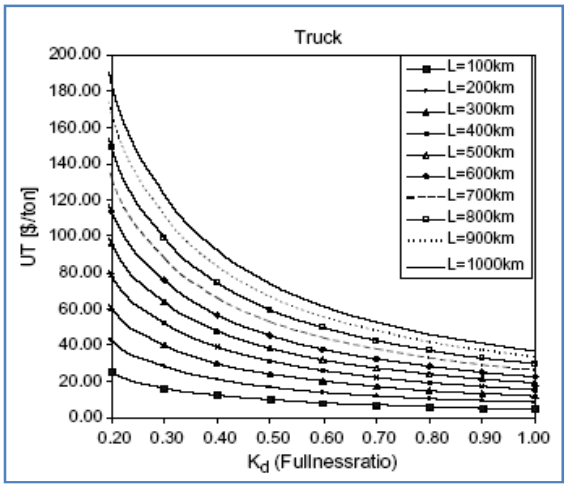

Figure 2.1Total transportation cost per unit of cargo for a truck with respect to fullness ratio. (100 < L< 1000 km) (Sahin *et al.,* 2009)

Gül and Elevli (2006) studied the solution of transportation problem of a cement plant with linear integer programming. The aim of the study is to investigate the cost advantage if transportation task is assigned to a contractor. Integer linear programming is used to decide a truck fleet that should be owned by the contractor. The main inputs to the program are the distance of a dealer to the plant, the number of dealers and cost items for three different capacity trucks. Truck capacities in the fleet are determined as stated legislation of Turkish Highway Traffic Law for freight transportation in the study. Total cost is computed summing up of fixed and variable cost items in the model. Fixed cost items are depreciation cost, interest cost, insurance cost and administrative cost whereas variable cost items are fuel cost, tire cost, repair and maintenance cost and labor cost. The full consumption rate of the trucks is assumed as shown in Table 2.1 in the model.

The objective function is formulated by Gül and Elevli (2006) to minimize the cost of transportation and the constraints are decided to be supply-demand balance constraints and non negativity constraints. The model is solved through the Tora and QSB computer programs. It is concluded by Gül and Elevli (2006) that 35.1 %

cost advantage is achieved if the task of transportation of cement from plant to dealer is assigned to a contractor.

Table 2.1The specifications of trucks related their capacities. (Gül and Elevli, 2006)

Capacity (tonne)	Investment Cost ($)	Motor Power (kW)	Fuel Consumption (lt/km)*
24	99,629	221	0.320
16	63,648	172	0.265
10	38,677	110	0.182

*The amount of fuel consumption of the truck if constant speed is 60 km/hr, slope is 10% and while it is fully loaded. (In Turkey, the slope of 98 % of highways is 10%.)

In the study of Özenen (1998), a survey is conducted to calculate vehicle operating cost of transportation (i.e. transportation by trucks) from Fethiye to Ankara and the results are compared to General Directorate of Highways (KGM) values and other vehicle operating cost models performed in Brazil, Kenya and Caribbean. In the study, vehicle speed, fuel cost, tire cost, maintenance cost, lubricant cost, depreciation cost and wage is computed. The variation in operating cost of transportation with respect to change in road characteristics is examined. It is seen that poor road and vehicle conditions of these countries resulted with huge cost values compared the survey results between Fethiye and Ankara.

Vehicle operating cost under variety of vehicle and road conditions is studied by Yıldız (1995). The relationships in the study is taken from Kenya, Brazil and Caribbean models and modified according to local conditions in Turkey and model is combined in a computer program. The name of the software is VOC. Calculations are provided twelve vehicle types ranging from small car to articulated truck in this study. The followings are concluded:

- Increase in surface roughness has an adverse effect on vehicle speed,
- At a given speed, vehicle load has an incremental effect on fuel consumption,

- The effect of vehicle load and gradient on tire wear are particularly strong,
- Vehicle operating cost is larger when vehicle is loaded than in when it is unloaded.

The point is stressed by Yıldız (1998) that road roughness is one of the most important road characteristics that affects almost all of vehicle operating cost components.

Shih (1997) studies planning of fuel coal imports using mixed integer programming method. In his model there are multiple coal supply points and multiple coal demand points which are power plants. Low quality and inexpensive coal is blended with high quality and expensive coal before delivering to a power plant in his study. Shih (1997) generates his objective function to minimize total cost of procurement, transportation and holding. CPLEX is used to solve the mixed integer-programming problem in his study.

A new methodology is suggested by Dullaert *et al.* (2005) for determining the optimal mix of transport alternatives to minimize total logistics costs when goods are shipped from a supplier to a receiver. It is assumed by Dullaert *et al.* (2005) that only a limited number of transport alternatives are available and entire capacity of a transport alternative is used to ship the goods from supplier to receiver. Dullaert *et al.* (2005) uses evolutionary algorithm to solve the problem and tests the heuristics on real life problem instances. It is concluded by Dullaert *et al.* (2005) that using construction algorithm or cross-over operators that guarantee feasible solution but no guarantee to find high quality solutions in the fastest and most efficient way.

CHAPTER 3

ABOUT TKİ AND COAL TRANSPORTATION DEMAND

Turkish Coal Enterprises (TKİ), a state enterprise, is the largest lignite producer of Turkey. Turkish Coal Enterprises (TKİ) delivers coal to all cities of Turkey in the context of a Prime Ministry Social Solidarity and Aid Fund every year. In this chapter the coal demand of the cities and coal transportation alternatives are explained.

3.1 TKİ and Prime Ministry Social Solidarity and Aid Fund

Coal delivered in the context of Prime Ministry Social Solidarity and Aid Fund is provided from both TKİ's mines and the mines exploited by private companies. The percentage of coal amount provided by TKİ and private companies in 2008 is illustrated in Figure 3.1.

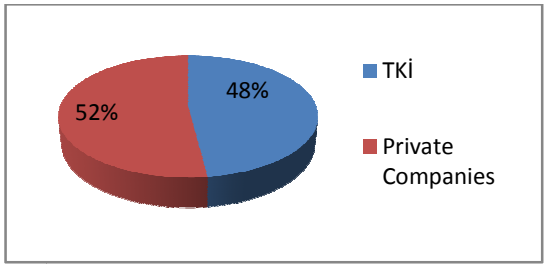

Figure 3.1The percentages of coal amount provided by mines of TKİ and private companies in 2008.

The coal amount provided in this context with respect to years and names of the mines is shown in Table 3.1. A graph illustrating delivered coal amount by TKİ between the years 2003 and 2008 is given in Figure 3.2.

Table 3.1The amount of coal delivered with respect to years and mines in the context of Prime Ministry Social Solidarity and Aid Fund by TKİ.

	2003	2004	2005	2006	2007	2008
	Coal (tonne)	Coal (tonne)	Coal (tonne)	Coal (tonne)	Coal (tonne)	Coal (tonne)
ELİ	363,323	350,845	364,161	313,554	364,367	373,401
GLİ	105,590	172,091	292,865	343,122	323,300	380,781
GELİ	10,159	17,347	20,505	18,930	22,510	0
SLİ	36,768	14,222	12,337	6,353	4,719	3,661
ÇLİ	23,994	28,710	31,378	66,921	45,070	15,443
BLİ	7,333	1,722	1,800	1,640	1,929	1,200
ILİ	30,353	28,642	0	0	0	0
GÖLİ	25,456	21,213	24,125	0	0	0
ŞIRNAK-GELİŞ	45,707	211,197	248,453	238,675	266,207	321,228
ÇELİKLER	14,037	144,068	174,523	189,888	266,310	259,994
KİAŞ	0	2,070	5,998	11,750	56,231	88,293
Y.ÇELTEK	0	0	0	23398	43,121	67,816
E.ÇELTEK	0	0	12,616	0	0	0
DUMAN BİRLİK	0	0	850	2,651	0	3,714
BÜKKÖY	0	0	4,703	7,098	2,912	14,765
ULUÇAYIR	0	0	750	0	0	1,061
SEÇKİN	0	0	3,471	3,810	8,582	3,773
AKALIN	0	0	1,000	1,900	2,500	1,202
AKİFOĞULLLARI	0	0	3,571	0	8,656	5,862
OLTU	0	12,646	27,962	18034	28,946	31,143
ALEMDAR	0	0	11,800	0	0	0
UYSAL	0	0	10,638	0	0	0
A.ARGAN	0	0	12,850	0	0	0
AKPINAR	0	0	10,080	3050	0	0
SEBA	0	21,197	22,876	11,616	300	0
POLAT	0	0	10,601	0	0	0
BİLGİN	0	2,150		0	0	0
DURAKSAN	0	8,115		0	0	0
A.ORAL	0	10,696	8,678	0	0	0
AKSA	0	0	0	0	26,755	43,993
YAMAÇ	0	0	0	0	0	3,000
CANTAŞ	0	0	0	0	0	7,290
TOPLAM	597,44	412,139	571,419	511,870	710,520	853,133
TOTAL	**662,720**	**1,046,931**	**1,318,590**	**1,262,390**	**1,472,415**	**1,627,619**

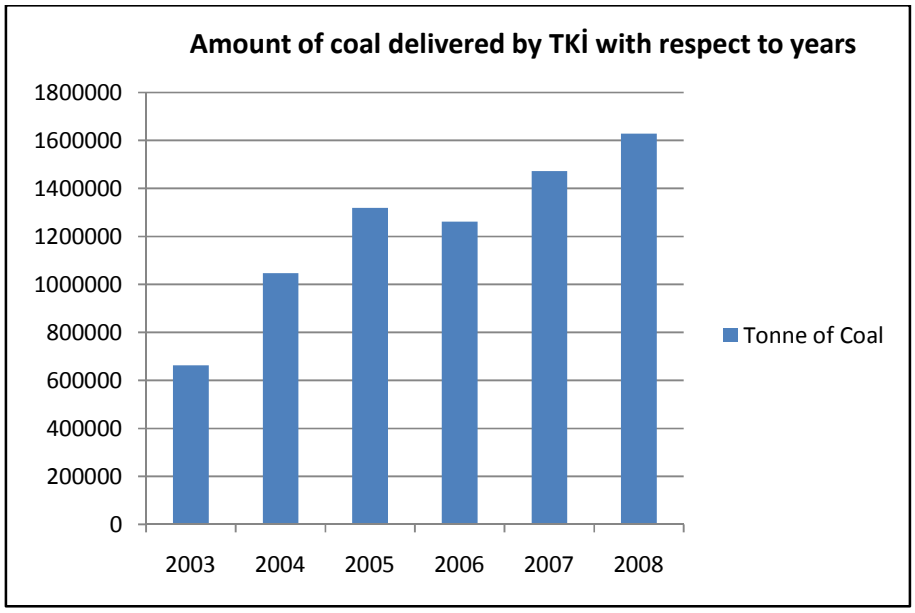

Figure 3.2 Total amount of coal delivered by TKİ with respect to years in the context of Prime Ministry Social Solidarity and Aid Fund.

3.2 Transportation Alternatives of Coal

Local authority of each city defines the needed coal amount of the province and informs TKİ about the transportation period and destination point.

Demanded coal by the cities can be delivered as packed or unpacked forms. Stockpiling of coal in the mine may also be needed as intermediate station. The coal can also be transported from mine directly without any packing or stockpiling.

TKİ is responsible for delivering the needed amount of coal defined by provinces to the destination points in time and hence, controls the contractors. An approximate transportation cost data is needed to evaluate the proposals given by the contractor. The cost of material handling and cost of transportation is computed through the developed software. The subsystems defined above constitutes the modular structure of developed software as presented in Chapter 5. The total cost is

computed in developed software by summing up of all the costs of subsystems pertinent to an alternative.

This demanded coal can be transported using different transportation alternatives. Transportation by ship or railway transportation can also be used as alternative to highway transportation. The transportation alternatives of coal starting from coal mine up to destination points are shown in Figure 3.3.

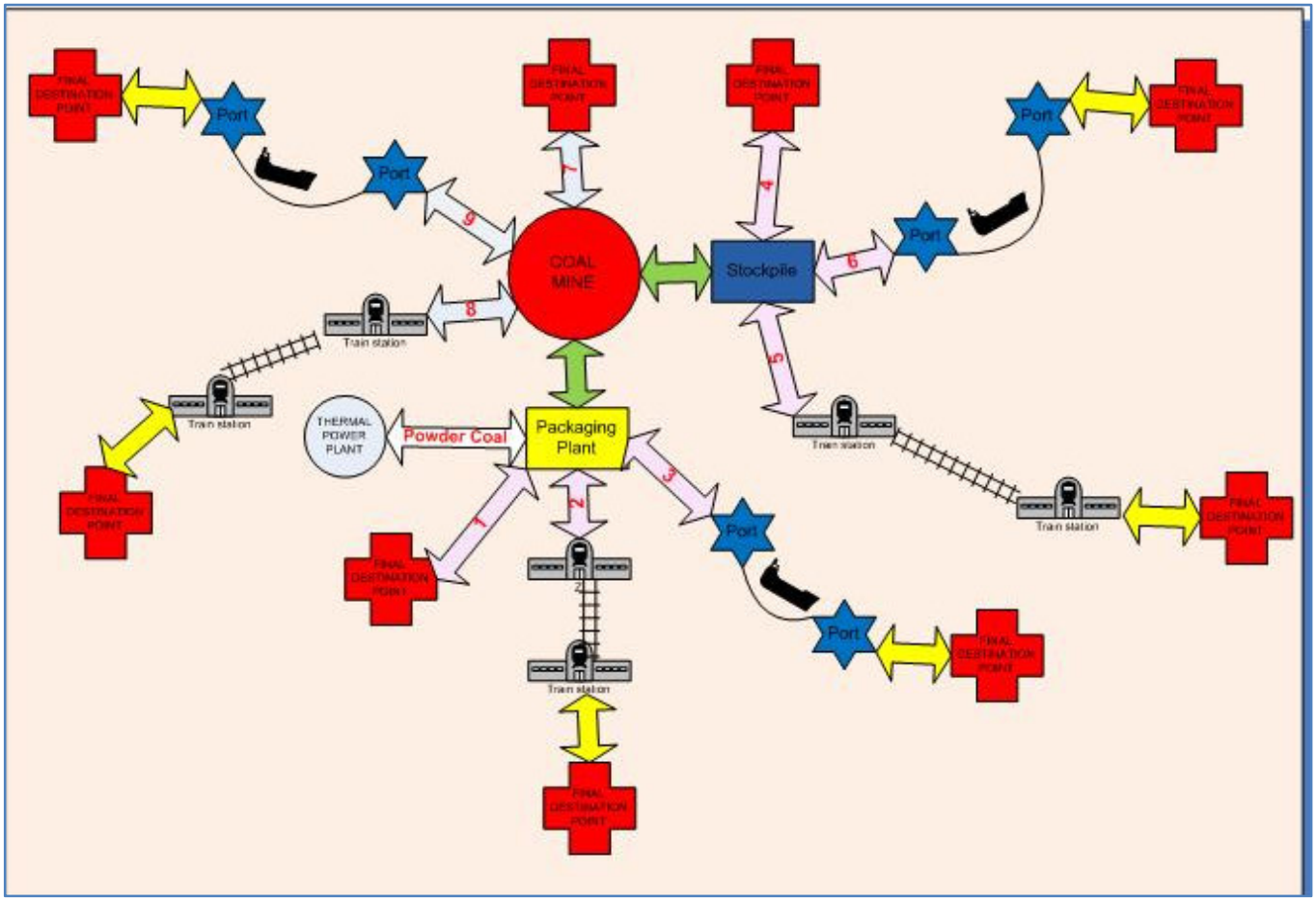

Figure 3.3 Schematic diagram of transportation alternatives.

The main alternatives for delivering coal to a destination point are numbered and in Figure 3.3 and described,

- Alternative 1: The loaded coal in the mine is transported to packing plant by trucks. Coal is packed and the packed coal is reloaded to trucks to be delivered to final destination point.

- Alternative 2: The loaded coal in the mine is transported to packing plant by trucks. The packed coal is transported to a railway station and loaded to wagons. The coal transported by railway is unloaded from wagons at the station and loaded to trucks to be delivered to final destination point.

- Alternative 3: The loaded coal in the mine is transported to packing plant by trucks. Coal is packed and the packed coal is transported to a port and loaded to ships. Transported coal by ships is unloaded in another port and loaded to trucks to be delivered to final destination point.

- Alternative 4: The loaded coal in the mine is transported to stockpile area by trucks. A loader is used to reload the trucks and the coal is delivered to final destination point by trucks.

- Alternative 5: The loaded coal in the mine is transported to stockpile area by trucks. A loader is used to reload the trucks to deliver the coal to a railway station and loaded to wagons at the station. Transported coal by railway is unloaded from wagons at the other station and loaded to trucks to be delivered to final destination point.

- Alternative 6: The loaded coal in the mine is transported to stockpile area by trucks. A loader is used to reload the trucks to deliver the coal to a port and coal is

loaded to ships at the port. Transported coal by ships is unloaded in another port and loaded to trucks and delivered to final destination point.

- Alternative 7: The loaded coal to trucks in the mine is directly transported to final destination point. The road condition is considered inside the mine and highway segments.

- Alternative 8: The loaded coal to trucks in the mine is directly transported a railway station without packing and stockpiling. The coal is loaded to wagons and transported to another railway station. It is unloaded at the railway station and loaded to trucks to be delivered to final destination point.

- Alternative 9: The loaded coal to trucks in the mine is directly transported to a port without packing and stockpiling. The coal is loaded to a ship and transported to another port. It is unloaded at the second port and loaded to trucks to be delivered to final destination point.

- Powder Coal Transportation Alternative: Besides above main nine alternatives, transportation of constituted powder coal from packing plant to a power plant alternative is also considered.

In Figure 3.3, double sided arrows illustrate a transportation option by trucks.

3.3 Subsystems of Transportation Alternatives

The transportation alternatives described above is divided into *subsystems*. These subsystems also constitute the modular structure of developed software. These subsystems, whose costs are computed through developed software, can be listed as below:

- Excavation/Loading: This subsystem includes all work for loading of coal in the mine. It is illustrated as a circle in Figure 3.3

- Transportation in the Mine: It is the transportation through mine road segments and illustrated as green double sided arrows in Figure 3.3.

- Packing Plant: This subsystem includes all work utilized for packing of coal and illustrated as a yellow rectangle in Figure 3.3.

- Highway Transportation I: It is the transportation subsystem starting from a stockpile or a packing plant and ending at a railway station, or a port or a destination point. This subsystem is illustrated as pink double sided arrows in Figure 3.3.

- Highway Transportation II: It is the transportation subsystem starting from a railway station or a port and ending at a destination point. This subsystem is illustrated as yellow double-sided arrows in Figure 3.3.

- Direct Transportation from Mine: It is the transportation subsystem including both mine road segments and highway segments. This subsystem starts at mine and ends at a railway station, or a port or a destination point and illustrated as light blue double-sided arrows in Figure 3.3.

- Stockpiling: This subsystem includes all work utilized for loading of coal to trucks in stockpile area and illustrated as a blue rectangle in Figure 3.3.

- Railway Transportation: This subsystem includes all work including loading of coal at a railway station, applying bale clothes to wagons, unloading of coal at railway station and transporting of coal by train.

- Transportation by Ship: This subsystem includes all work including loading of coal to a ship in a port, transportation of coal by a ship and unloading of coal at another port.

- Loading of Powder Coal: This subsystem gains meaning if packing is applied and includes all work utilized for loading of powder coal to trucks at packing plant.

- Transportation of Powder Coal: It is the transportation of powder coal to power plant. This subsystem includes both mine road segments and highway segments. Loading and transportation of powder coal is illustrated as double sided white arrow in Figure 3.3.

CHAPTER 4

FUNDAMENTALS OF NAKMAL SOFTWARE

Before giving the concept and model formulation of the developed software, the structure of the software and the database is summarized in this chapter.

4.1 Database Structure

The database of the developed software is outside of the code and hence can easily be updated. The database is created by using Microsoft Access and must be kept in drive C of a computer to be able to run the software. The names of the tables in database are listed in Table 4.1 and tables are given in Appendix A (Karpuz *et al*., 2008).

Table 4.1 Names of tables in the database

1	Excavator Descriptions
2	Loader Descriptions
3	Truck Descriptions
4	Packing Plant Descriptions
5	Rolling Resistance Descriptions
6	Fuel Consumption in the Mine
7	Unit Fuel Price Description
8	Employer Descriptions
9	Unit Electricity Cost Description
10	Auxiliary Equipment Description

Data collection for the equipments in the fleet is utilized through making contact with the producer companies and by catalogues. The equipment data gathered from different companies are used to specify the features of equipment.

Material handling equipment selection is verified assuming that the coal has already been loosened by explosives and no need to material preparation like drilling,

blasting or ripping. Since contractors mostly use hydraulic excavators and rubber tired loaders, research has been focused on the specification of these type equipments. Hydraulic excavators and rubber tired loaders having 2-7 m^3 bucket capacities are selected for loading equipment fleet. The specifications of loading equipment fleet are given in Table A.1 and Table A.2 in Appendix A.

Truck capacity range is determined according to capacity of loading equipment fleet. The principle in deciding the truck capacity range is number of passes restriction which is 4-7. The specifications of truck fleet are given in Table A.3 in Appendix A.

List of available packing plants and related data about their features are received from TKİ and given in Table A.4 in Appendix A. In the case of any change in capacity or other features of packing plant, the data can easily be updated. Roads are classified according to their physical characteristics and rolling resistance values in different road conditions are given in Table A.5 in Appendix A. A dozer may be used as an auxiliary equipment to support loading process and its specifications are given in Table A.6 in Appendix A. The fuel consumption rates of trucks in the mine with respect to total resistance are tabulated in Table A.7 in Appendix A. Unit fuel cost, unit electricity cost and labor salaries are given in Table A.8, Table A.9 and Table A.10 in Appendix A.

4.2 Menus and Submenus of NAKMAL

NAKMAL has four menus shown in Figure 4.1. Their names are *File, Descriptions, Reports and About.* File operations are verified through *File* menu, database is reached through *Descriptions* menu and print reports are displayed through *Reports* menu. The submenus of these *File, Description and Reports* menus are shown in Figures 4.4, 4.5 and 4.6.

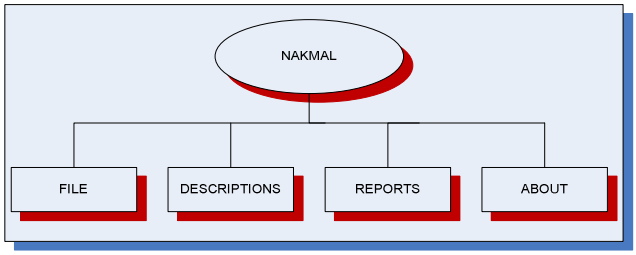

Figure 4.1 Menus of NAKMAL

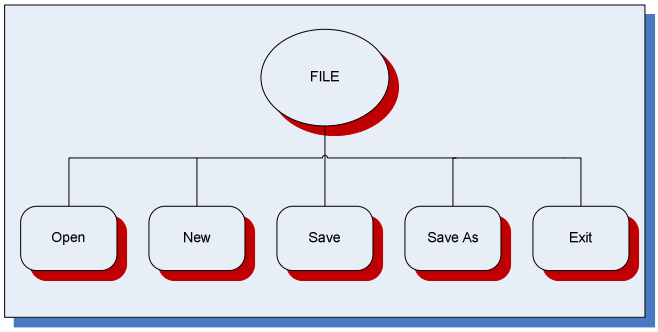

Figure 4.2 Submenus of *File* menu

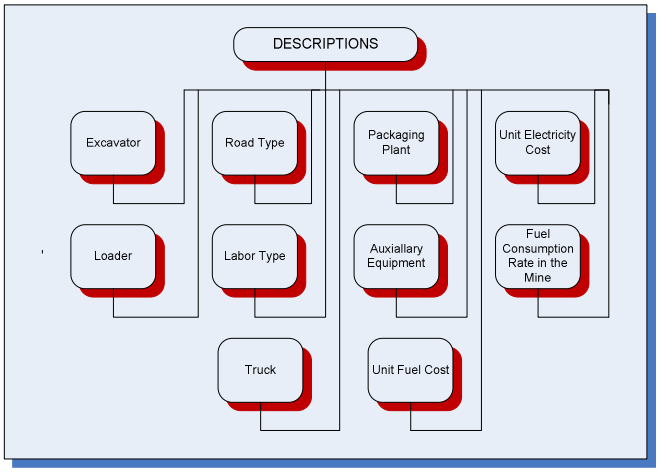

Figure 4.3 Submenus of *Description* menu

Figure 4.4 Submenus of *Reports* menu.

4.3 Modules of NAKMAL

The software has 19 modules to calculate the cost of subsystems mentioned in Chapter 2. The names of the modules are given in Table 4.2.

Table 4.2 Names of the modules in NAKMAL

1	General Information
2	Excavator/Loader Selection
3	Excavation/Loading Cost
4	Truck Selection for Mine Transportation
5	Cost of Transportation Inside the Mine
6	Packing Plant
7	Cost of Loading from Stockpile
8	Equipment Selection for Highway Transportation I
9	Cost of Highway Transportation I
10	Railway Transportation Cost
11	Transportation Cost by Ship
12	Truck Selection for Highway Transportation II
13	Cost of Highway Transportation II
14	Truck Selection for Direct Transportation in Mine
15	Cost of Direct Transportation from Mine
16	Powder Coal Loading Cost
17	Truck Selection for Powder Coal Transportation
18	Powder Coal Transportation Cost
19	Total Cost Module

4.4 Assumptions in the Model

The operating cost values calculated through the software are valid under some assumptions. The assumptions valid for all modules are salvage value coefficient, discount rate, spare part cost coefficient, repair and maintenance cost coefficient and unexpected cost. In calculating depreciation cost, salvage value of the equipments and plant is assumed to be 20%. The discount rate is assumed to be 12% in calculation of interest cost. Spare parts are assumed to be 25% of depreciation cost. Similarly, maintenance and repair cost is assumed to be 10% of depreciation cost. Unexpected costs for material handling and transportation cost units are assumed to be 2% of depreciation cost. The deprecation times for the plant and equipment are assumed to be as given in Appendix A.

Excavation or loading equipment selection is verified among the different capacities given in Table A.1 and Table A.2 in Appendix A through the software. The excavator or loader capacities meeting the required production amount is decided by the software. In addition to this, calculations according to any loader or excavator which is selected by the user can be verified. In calculations, different working conditions are reflected to model by efficiency factor, dipper factor for both loader and excavator but depth of cut correction factor and angle of swing factor only for excavator. Life of a loader tire is assumed to be 8000 hours in tire cost calculation of loading equipment.

Capacities of trucks loaded by excavator or loader are restricted with 4-7 maximum passes of loading equipment. The necessary number of trucks computation for trucks loaded by an excavator or loader is verified by the software in a way that waiting time of loading equipment is minimized. The life of a truck tire is assumed to be 2000 hours for mine road segments and 2500 hours for highway segments. These assumptions are made based on TKİ experimental data. While fuel consumption rates are assumed to be 0.32 lt/km for highway segments, the fuel consumptions rate values in Table A.7 in Appendix A are used for the consumption through mine road segments.

For estimating speed of the trucks in mine road segments, regression equations are fitted to provide a common basis for the model. Since, inputting the grade and rolling resistance of all highway segments from a mine to a destination point is difficult, constant speed is assumed through highway segments in the model. It is assumed that the average constant speed is 70 km/hr for empty trucks and 50 km/hr for loaded truck.

The coal packing cost can be computed by NAKMAL for different capacity plants given in Table A.4 in Appendix A. Packing plant working conditions are reflected to the model by the efficiency factor. The repair and maintenance cost of the plant is

assumed to be 10% of electricity cost of the plant. This assumption is based on TKİ's experimental data. Schematic diagram of the NAKMAL is shown in Figure 4.5.

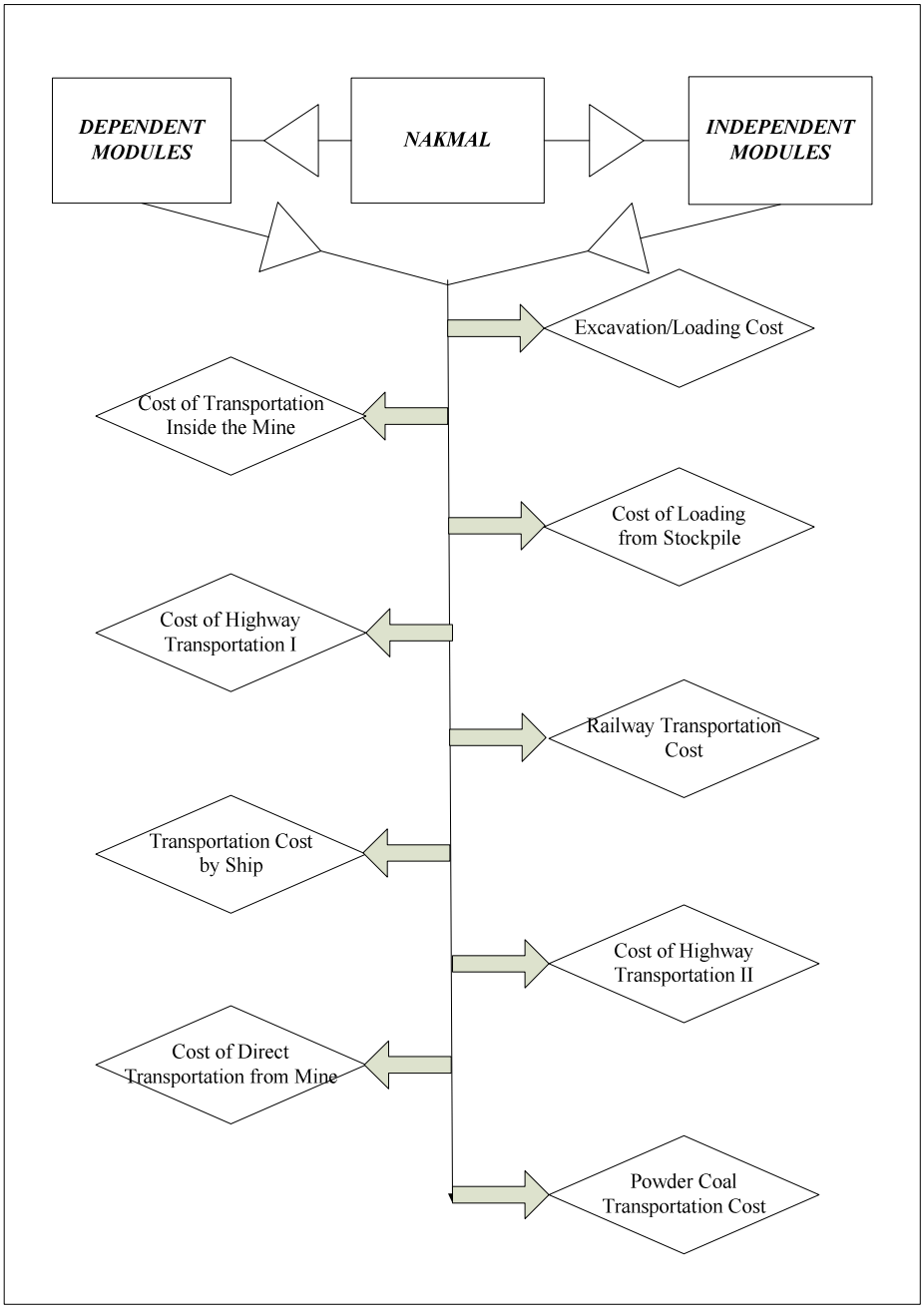

Figure 4.5. Schematic Diagram of NAKMAL

CHAPTER 5

THE PROPERTIES OF NAKMAL

The software, called NAKMAL which is an abbreviation using first three letters of *transportation cost* in Turkish *"Nakliye Maliyeti"*, is coded in Microsoft Visual Studio.NET 2005 in order to carry out operational cost of excavation/loading and transportation and create a simple tool for the engineers to compute cost of excavation/loading and transportation cost.

5.1 Introduction to NAKMAL Software

NAKMAL starts with welcome page as shown in Figure 5.1. User click the button "*Click to Start NAKMAL"* to start the program.

Figure 5.1Appearance of *Introduction Page* of NAKMAL

5.2 Module 1: General Information Module

The appearance of the module is as shown in Figure 5.2. There are two text boxes at the top of the window to name and describe project. The inputs of the module are production amount, actual working time, project time, swell factor and the unit weight of the coal and powder coal. The software can be run in two ways. The first option is called *Dependent Modules* and prepared to compute optimum cost and the other one is called *Independent Modules* and prepared for use of TKİ. *Dependent Module* option is explained in this chapter. The interface of the *Dependent Module* option is as shown in Figure 5.2 and *Independent Module* option is as shown in Figure 5.3. The specifications of the work are defined by checking the radio boxes or check boxes shown in Figure 5.2 and 5.3. If powder coal transportation is checked, the unit weight of the powder coal panel is displayed and the value is entered. "*Click to Continue with the Tabs"* button is clicked and corresponding tabs are displayed just below the menu bar as shown in Figure 5.2.

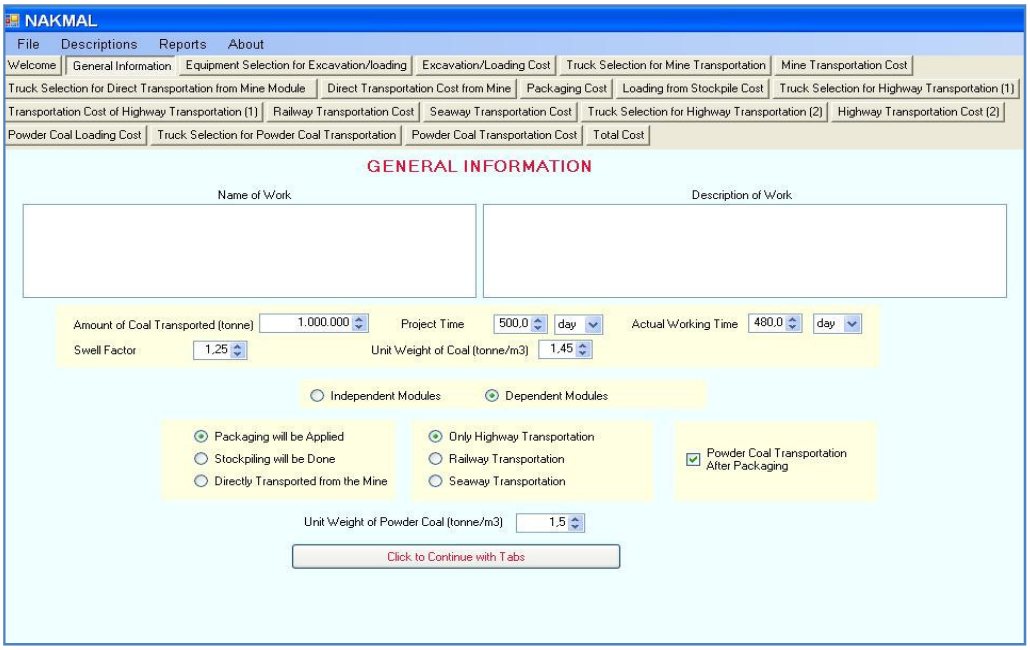

Figure 5.2 Appearance of *General Information Module*, if *Dependent Modules* option is selected.

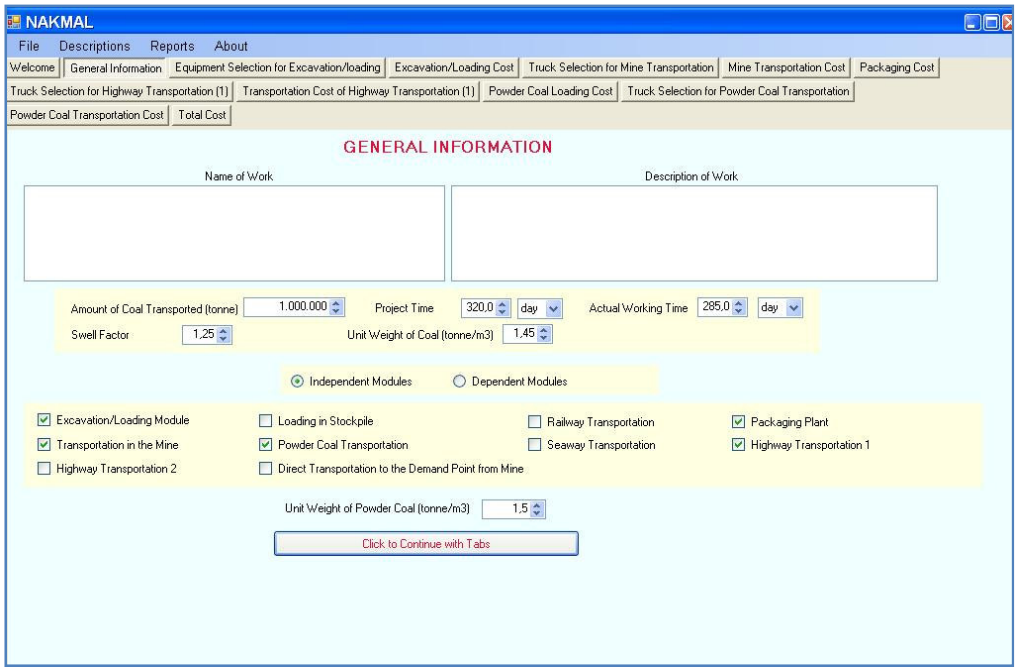

Figure 5.3 Appearance of *General Information Module*, if *Independent Modules* option is selected.

5.2.1 Transportation Amount

Transportation amount is the total coal amount, which is planned to transport the destination point. The losses during packing of coal are calculated by the software. During packing process 15% of coal is considered to be separated as powder coal (Karpuz *et al.*, 2008). If packing process is not applied, then the transportation amount is the same as the demanded coal amount by the cities. If packing process is applied, then the transportation amount is more than the demanded coal amount due to losses during packing process and it is calculated using equation 5.1.

$$P_d = P_p * (1 - pp) \tag{5.1}$$

where,

P_d: Amount of coal demanded (tonne)

P_p: Amount of coal produced (tonne)

pp: Powder coal coefficient which is equal to 0.15

5.2.2 Project Duration and Actual Working Duration

There are two types of duration, which are specified separately in the software. These are project duration and actual working duration. Both are defined in units of day, month and year. While defining actual working duration if year or month is selected then, the number of days in which there will be production during month or year is the new question asked to the user.

5.2.3 Dependent Module Algorithm

If dependent algorithm is selected then output of previous subsystem is taken as input to current subsystem. It affects especially the equipment selection. Since proper equipment selection is a major factor in decreasing cost, modules should be run dependently to end up an optimum cost.

5.2.3.1 Options in Dependent Module Algorithm

Related modules are displayed according to the selections among the below options
User selects among the transportation modes:

- Only Highway Transportation,
- Railway Transportation,
- Transportation by Ship.

Intermediate stations are defined by checking radio buttons, whether;

- The packing will be applied, or
- The stockpiling will be applied, or

- Directly transported from the mine.

If the "*packing will be applied"* radio button is checked, then powder coal transportation option panel is displayed, and then the unit weight of powder coal is asked to the user.

5.2.4 Independent Module Algorithm

This is an independent algorithm which has been designed for TKİ's working condition. No restriction that arising from pre operation is set to the user. All part of work is considered independently from each other and duration of all subsystems is extended to working duration of the project. Since some parts of whole work are assigned to a contractor, the modules are run independently.

5.3 Module 2: Excavator/Loader Selection

Appearance of the module is as given in Figure 5.4. This module is designed to select excavation or loading equipment capacity to satisfy the required production amount. The flow chart of this module is given in Figure 5.5. The first selection offered to the user is whether excavator or loader is used. In the selection of the second selection provided to the user is whether the offered equipment is used or equipment capacity is selected from the combo box by the user. Based on these selections, the selected bucket capacity of the excavator/loader is viewed and the calculations about production are computed and displayed.

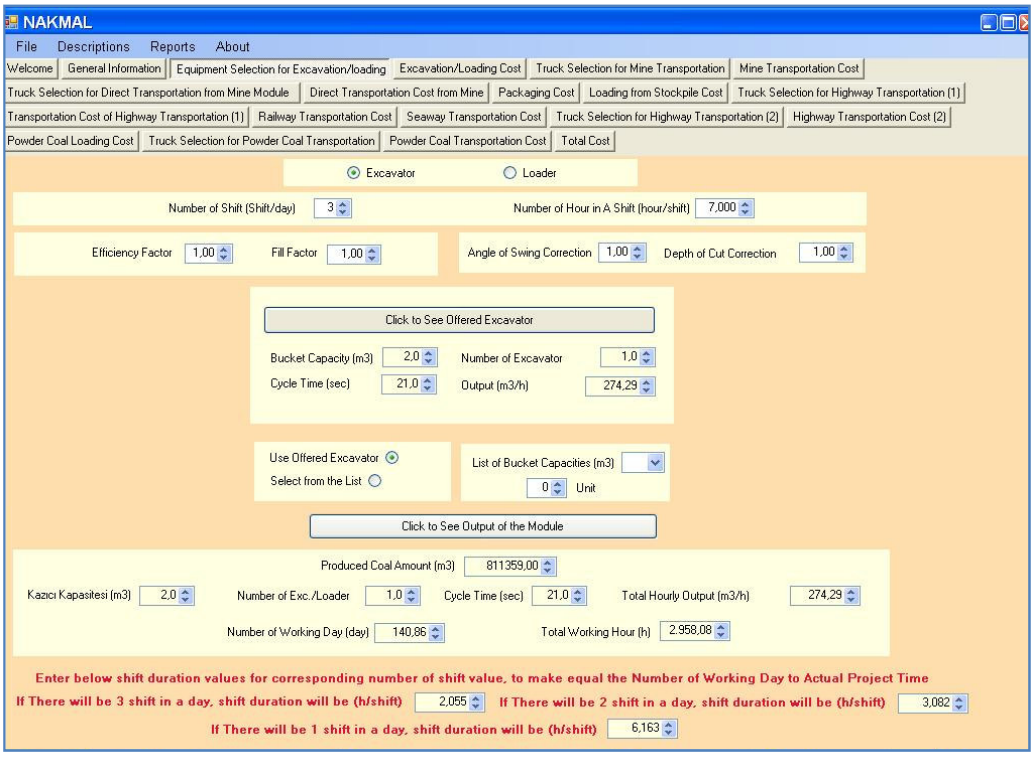

Figure 5.4 Appearance of the *Excavator/Loader Selection* module.

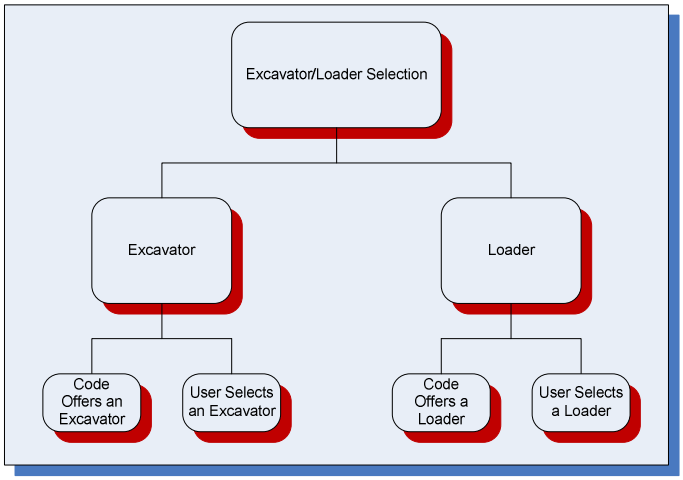

Figure 5.5 Flow chart of *Excavator/Loader Selection* module

5.3.1 Calculations for Suitable Excavator/Loader

After entering parameters described above, the software either offer a bucket capacity for an excavator/loader or the excavator/loader bucket capacity is defined by the user by a combo box. The algorithm in the software while offering a bucket capacity is calculating hourly production required to meet the production and maximum hourly production for all excavator alternatives and choosing the minimum capacity fitting the constraint.

5.3.1.1 The calculation of Maximum Hourly Production

The maximum hourly production that an excavator/loader can reach in stated conditions are calculated with the formulas given in equations 5.2 and 5.3. (Karpuz *et al*., 2005)

For a Loader:

$$C_d = \frac{Q * t_s * S}{3600 * E * F} \tag{5.2}$$

For an Excavator:

$$C_d = \frac{Q * t_s * S}{3600 * E * F * D * A} \tag{5.3}$$

where;

C_d: Bucket capacity of loading equipment (m^3)

Q: Hourly production in place (m^3/hr)

t_s: Cycle time of loading equipment (seconds)

E: Efficiency factor of loading equipment

F: Fill factor of loading equipment

S: Swell factor

D: Depth of cut correction factor

A: Angle of swing correction factor

Depth of Cut Correction Factor: It is used if equipment is working at a depth of cut other than optimum. The cycle time correction factors are given in Table 5.1 with respect to optimum depth of cut value (Karpuz *et al*., 2005). It is meaningful for excavators only. If loader is used this parameter is not considered and removed from the screen

Table 5.1 Depth of Cut Correction Factor (Karpuz *et al*., 2005)

Optimum Depth of Cut, %	40	60	80	100
Cycle Time Correction Factor	1.25	1.1	1.02	1

Angle of Swing Correction: It is used to correct the excavator cycle time based on a standard swing angle of 90.

Fill Factor (Dipper Factor): It is the approximate percent ratio of the material carried out in the bucket capacity and fill factor for some rocks are given in Table 5.2 (Karpuz *et al*., 2005). It is meaningful for both excavator and loader and determined in the field.

Table 5.2 Swell factor, fill factor and unit weight of some rocks (Karpuz *et al*., 2005).

Rock Type	Unit Weight (in place) (tonne/m^3)	Swell Factor	Fill Factor
Coal (Lignite)	1.00	1.30	0.90
Coal (Antrasite)	1.60	1.35	0.90
Coal (Bitimous)	1.25	1.35	0.90
Soil (Dry)	1.65	1.30	0.95
Soil (Wet)	2.00	1.30	0.90
Limestone	3.20	1.40	0.85
Limestone (Hard)	2.60	1.60	0.80
Limestone (Soft)	2.20	1.50	0.85
Shale	2.35	1.45	0.80

Efficiency Factor: It is used to reflect combine effect of availability of equipment and administrative quality. Availability is the time period that the equipment is ready for the production (Karpuz *et al*., 2008). Typical efficiency values are given in Table 5.3.

Table 5.3 Working efficiency values (Karpuz *et al*., 2005).

Working Condition	Administrative Efficiency			
	Perfect	Good	Fair	Poor
Perfect	0.83	0.80	0.77	0.77
Good	0.76	0.73	0.70	0.64
Fair	0.72	0.69	0.66	0.60
Poor	0.63	0.61	0.59	0.54

Swell Factor: Swell factor represents the percent increase in volume of a material from in place to loose state and used to calculate the volume of the coal after excavated or loaded and for calculation of the bucket capacity of the excavator or loader. It is input by the user depending on the swell factor of the coal. Swell factor values some rock types are given in Table 5.2.

Unit Weight: It is the weight per cubic meter of coal. It is used to convert coal volume to coal weight. It is again input by the user depending on the unit weight of the coal. Unit weight values some rock type is given in Table 5.2.

5.3.1.2 The Calculation of Hourly Required Production

Actual working duration of the excavator/loader is calculated in hourly basis. The number of working days in a year or in a month is used to calculate the actual work duration in hourly basis. Hourly required production to meet the project requirements is calculated using equation 5.4.

$$Q = \frac{P_d}{d * AT} \tag{5.4}$$

where,

Q: Hourly required production in place (m^3)

P_d: Amount of coal demanded (tonne)

d: Density of the coal (tonne/m^3)

AT: Actual working duration (hours)

5.3.2 Output of the Module

The following parameters are output of this module, for the selected configuration.

- The selected excavator or loader bucket capacity,
- The cycle time of selected excavator or loader,
- The number of excavators or loaders,
- The bunk volume of coal to be excavated or loaded,
- The required hourly output,
- The hourly output of selected configuration,

- The number of days and hours to complete the excavating/loading process according to inputs.

Besides the above outputs, there is an informative window at the bottom of the screen, showing the shift durations of and number of shifts one, two and per day, to shifty the production over the actual working time.

5.4 Module 3: Excavation/Loading Cost

Appearance of the Module is as shown in Figure 5.6. The calculated operating cost items in calculating Excavation/Loading Cost are depreciation cost, labor cost, fuel cost, oil cost, repair and maintenance cost, interest cost, spare parts cost and tire cost if loader is selected.

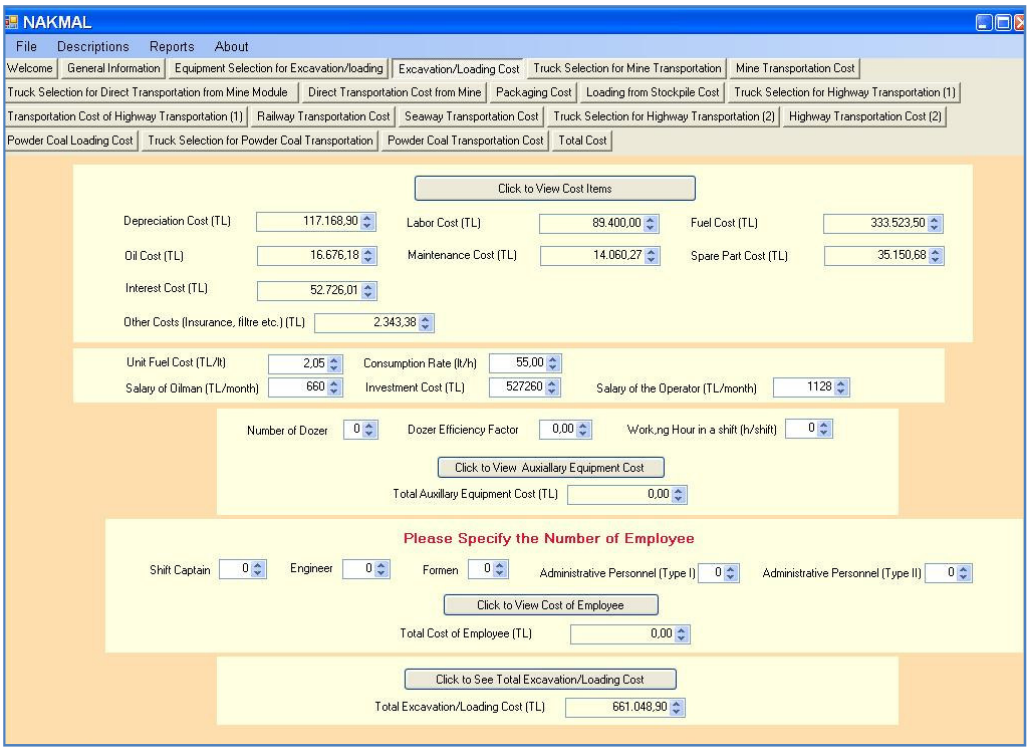

Figure 5.6 Appearance of *Excavation/Loading Cost* Module

5.4.1 Depreciation Cost of Loading Equipments

Depreciation cost of an excavator/loader is calculated using equation 5.5 (Karpuz *et al.*, 2008) The salvage amount is deducted from investment cost and salvage ratio is assumed to be 20%. Depreciation cost is multiplied with salvage value coefficient, which is equal to 0.8.

$$DC_e = \frac{I_e}{DT_e * 360} * Wd_e * sc * n_e \tag{5.5}$$

where,

DC_e: Depreciation cost of loading equipment (TL)

I_e: Investment cost of loading equipment (TL)

DT_e: Depreciation time of loading equipment (years)

n_e: number of loading equipment

Wd_e: Number of working days (days)

sc: Salvage value coefficient

5.4.2 Labor Cost in Excavation/Loading

It is the amount of value paid to labors during the working time. In this module one operator and one oilman is thought to be working for each excavator for every shift. If loader is used, oilman is not thought to be working and the salary of oilman is not computed. Then, the labor cost is computed using equation 5.6 for an excavator.

$$LC_e = \sum_i (\frac{Wd_e}{30} * Ns * S_i * n_e) \tag{5.6}$$

where,

LC_e: Labor cost in excavation/loading (TL)

i: index for labor types (operator, labor)

Wd_e: Number of working days for excavator/loader (days)

Ns: Number of shifts per day

S_i: Salary of i^{th} type labor (TL/month)

n_e: Number of loading equipments

5.4.3 Fuel Cost of the Loading Equipments

To calculate fuel cost, consumption rate and working time of excavator in hourly basis information is necessary. The working hours to meet the required production for the excavator/loader are output of previous module. In the database, the amounts of consumption rates for different machines are available. The fuel cost is then can be expressed as in equation 5.7.

$$FC_e = Cn_e * Wh_e * UCF * n_e \tag{5.7}$$

where,

FC_e: Fuel cost in loading (TL)

Cn_e: Fuel consumption of the loading equipment (lt/hr)

Wh_e: Number of total working hours of loading equipments (hr)

UCF: Unit cost of fuel (TL/lt)

n_e: Number of loading equipments

5.4.4 Oil Cost of the Loading Equipments

Oil cost is assumed to be 5% of total fuel cost (Karpuz *et al.*, 2008).

5.4.5 Tire Cost of the Loader

The tire price of a loader is specified in the database in Appendix A. Number of tires of a loader is taken as 4 and tire cost is calculated using equation 5.8 (Karpuz *et al.*, 2008).

$$TC_l = TP_l * \frac{Wh_e}{8000} * nt_l * n_l \tag{5.8}$$

where,

TC_l: Tire cost for loader (TL)

TP_l: Price of a loader tire (TL/tire)

Wh_e: Number of working hours of loading equipment (hours)

nt_l: Number of tires of a loader

n_l: Number of loaders

5.4.6 Repair and Maintenance Cost of the Loading Equipments

It is approximated as 10% of depreciation value of excavator or loader (Karpuz *et al.*, 2008).

5.4.7 Spare Part Cost of the Loading Equipments

It is approximated as 25% of depreciation value of excavator or loader (Karpuz *et al.*, 2008).

5.4.8 Interest Cost of the Loading Equipments

The yearly discount rate is assumed to be 12%, in the software. It is computed using equation 5.9 (Karpuz *et al.*, 2008). Depreciation time is assumed to be 5 years in calculations.

$$IC_e = I_e * \frac{DT_e + 1}{2 * DT_e} * dr * \frac{Wd_e}{360} * n_e \quad (5.9)$$

where;

IC_e: Interest cost of the loading equipment (TL)

I_e: Investment cost of the loading equipment (TL)

DT_e: Depreciation time of the loading equipment (years)

Wd_e: Number of working days for the loading equipment (days)

dr: Discount rate

n_e: Number of the loading equipments

5.4.9 Auxiliary Equipment Cost

A dozer may be needed to help production. The features of the dozer are described in the database. The cost items are same in Excavation/Loading Cost items above and calculated in the same manner.

5.4.10 Employer Cost

The number of mine managers, engineers, formens, and officers are described in the module. The salaries of them are in database. The employer cost is then calculated using equation 5.10 (Karpuz *et al.*, 2008).

$$EC_e = \sum_j \left(\frac{Wd_e}{30} * n_j * S_j\right) \quad (5.10)$$

where,

EC_e: Employer cost in loading (TL)

j: Employer type (Mine manager, engineer, formen, officers)

Wd_e: Number of working days of loading equipment (days)

n_j: Number of j^{th} type employers

S_j: Salary of j^{th} type employer (TL)

5.5 Module 4: Truck Selection for Transportation inside the Mine Module

The excavated or loaded coal in the mine is either transported to packing plant or directly to the demand point or to a stockpile to be transported later. This module is displayed if "*Packing will be Applied"* or "*Stockpiling will be Applied"* option in General Information Module is selected. In this module, the equipment is selected to transport the coal produced by the excavator/loader to packing plant or a stockpile. Truck and excavator/loader match is important to reach optimum point. The number of swings for an excavator/loader to fill a truck is 4-6 in optimum case. Hence, truck capacities are limited and suitable trucks are listed according to their load capacities to meet the number of swings constraint of loader to fill a truck. Maximum 12 segments for a mine road can be defined by the user.

The items which are inputs and defined by the user are,

- Fill factor of truck,
- Efficiency factor of truck,
- Maneuvering time in loading,
- Maneuvering time in dumping and dumping time.

The items calculated in the module are:

- Loading Time,
- Number of swings,
- Cycle time of the truck,
- Number of Trucks.

5.5.1 Number of Swing and Loading Time Calculations

The number of swings to fill the truck and loading time is calculated using equations 5.11 and 5.12.

$$SN = \frac{Cp_T}{C_d} \tag{5.11}$$

$$t_l = \frac{SN * t_s}{60} \tag{5.12}$$

where,

SN: Swing number

Cp_T: Capacity of the trucks (tonne)

C_d: Bucket capacity of the loading equipment (tonne)

t_s: Cycle time of the loading equipment (seconds)

t_l: Loading time (minute)

5.5.2 Calculating Cycle Time of the Truck

To calculate cycle time of the selected truck, equation 5.13 is used (Karpuz *et al.*, 2008)

$$t_T = \frac{(t_l + t_p + t_h + t_d + t_f)}{60} \tag{5.13}$$

where,

t_T: Truck cycle time (hr)

t_l: Truck loading time (min)

t_p: Maneuvering time before loading (min)

t_h: Transport time while truck is loaded (min)

t_d: Maneuvering and dumping time (min)

t_f: Returning back time for loading (min)

To calculate transportation time for loaded truck the speed of the truck should be known. To calculate the speed of the truck road condition should be known. Road condition is expressed in terms of total resistance Total resistance is sum of grade resistance and rolling resistance. The grade resistance is entered by the user in percent out of 100. The road type is selected according to mine road condition by a combo box and corresponding rolling resistance value is displayed. The rolling resistance for different road types is given in Appendix A.

The user select one of the road types by a combo box and the total resistance is calculated according to equation 5.14 (Karpuz *et al.*, 2008).

$$TR = RR + GR \tag{5.14}$$

where,

TR: Total resistance (%)

RR: Rolling Resistance (%)

GR: Grade Resistance (%)

Total Resistance versus truck speed relation is given in Figure 5.7.

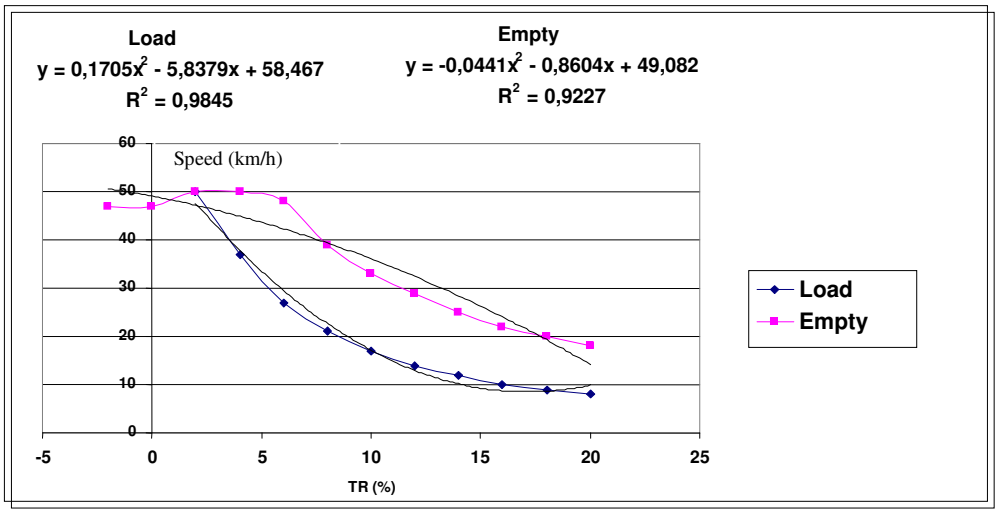

Figure 5.7 Speed of the truck and total resistance relation. (Karpuz *et al*., 2008)

After finding the speed of the trucks, transport time both loaded and empty state is calculated dividing the distance to the speed.

Other time components of cycle time which are preparing time for loading (t_l) and maneuvering and dumping time (t_d) are defined by the user. Hence cycle time for selected truck can be computed.

5.5.3 Number of Trucks Calculation

The number of shifts that trucks are worked in a day is determined by the user by means of a combo box. The hourly output of a truck is then calculated using equation 5.15 (Karpuz *et al.*, 2008).

$$Pr_T = \frac{Cp_T * F_T * E_T}{t_T} \tag{5.15}$$

where,

Pr_T: Productivity of the truck (tonne/hr)

Cp_T: Capacity of the truck (tonne)

F_T: Fill Factor of the truck

E_T: Efficiency factor of the truck

t_T: Cycle time of the truck (hr)

Then the number of trucks needed is computed using the equation 5.16 (Karpuz *et al.*, 2008). The result is rounded to next bigger integer number if the decimal part is equal or greater than 25.

$$n_T = \frac{Pr_e}{Pr_T} \tag{5.16}$$

where,

n_T: Number of trucks

Pr_e: Productivity of the loading equipment (tonne/hr)

Pr_T: Productivity of the truck (tonne/hr)

5.6 Module 5: Cost of Transportation Inside the Mine

Appearance of the module is as shown in Figure 5.8. The components of operating cost of transportation are depreciation cost, labor cost, fuel cost, oil cost, tire cost, spare part cost, repair and maintenance cost, and Interest cost.

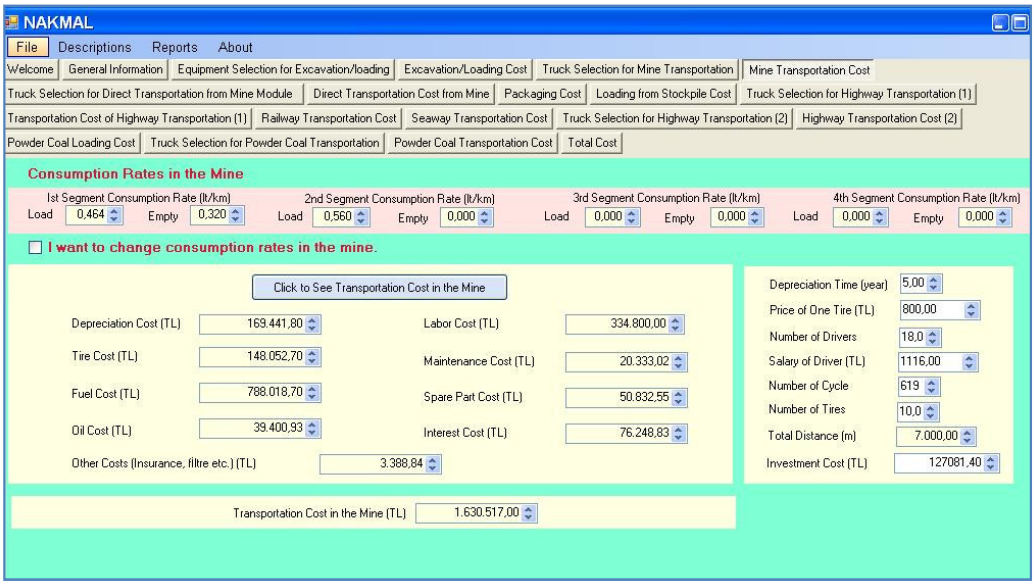

Figure 5.8 Appearance of *Mine Transportation Cost* Module

5.6.1 Depreciation Cost of Trucks

The depreciation cost can be computed by equation 5.17 (Karpuz *et al.*, 2008). Salvage value is assumed to be 20% of investment cost. Depreciation time is defined in database in units of years.

$$DC_T = \frac{I_T}{DT_T * 360} * Wd_T * sc * n_T \tag{5.17}$$

where,

DC_T: Depreciation cost of trucks (TL)

DT_T: Depreciation time of trucks (years)

I_T: Investment cost of selected truck (TL)

n_T: Number of trucks

Wd_T: Working time of trucks (days)

sc: Salvage value coefficient

5.6.2 Labor Cost in Transportation by Trucks

The salary paid to the truck driver during transportation is the labor cost. One driver is assigned for every shift. The number of drivers is then calculated using equation 5.18.

$$n_d = n_s * n_T \tag{5.18}$$

where,

n_d: Number of truck drivers

n_s: Number of shifts in a day

n_T: Number of trucks

Then the labor cost is computed using equation 5.19.

$$LC_T = n_d * \frac{Wd_T}{30} * S_d \tag{5.19}$$

where,

LC_T: Labor cost in transportation by trucks (TL)

n_d: Number of truck drivers

S_d: Salary of truck driver (TL)

Wd_T: Number of working days of the truck (days)

5.6.3 Fuel Cost of Trucks

The fuel consumption of the truck is related with total resistance and the relation between total resistance and fuel consumption is given in Appendix A. Fuel cost is calculated using equation 5.20.

$$FC_T = Cn_T * x * n_c \tag{5.20}$$

where,

FC_T: Fuel cost for transportation (TL)

Cn_T: Consumption rate of the truck (lt/km)

x: Distance of a truck cycle (km)

n_c: Number of cycles for all trucks

5.6.4 Oil Cost of Trucks

It is assumed to be 5% of fuel cost (Karpuz *et al.*, 2008).

5.6.5 Tire Cost of Trucks

The price and number of tires are defined in the database. The life of tire is assumed to be 2000 hours for mine roads. The tire cost is then computed using equation 5.21 (Karpuz *et al.*, 2008).

$$TC_T = nt_T * TP_T * \frac{Wh_T}{2000} \tag{5.21}$$

where,

TC_T: Tire cost of trucks (TL)

nt_T: Number of tires for the truck

TP_T: Price of one tire (TL)

Wh_T: Number of total working hours of all trucks (hr)

5.6.6 Spare Parts Cost of Trucks

Cost of spare parts is assumed to be 25% of depreciation cost (Karpuz *et al.*, 2008).

5.6.7 Repair and Maintenance Cost of Trucks

Cost of spare parts is assumed to be 10 % of depreciation cost (Karpuz *et al.*, 2008).

5.6.8 Interest Cost of Trucks

Yearly discount rate is assumed to be 12% and interest cost is computed using equation 5.22a (Karpuz *et al.*, 2008).

$$IC_T = I_T * \frac{DT_T + 1}{2 * DT_T} * dr * \frac{Wd_T}{360} * n_T \quad (5.22a)$$

IC_T: Interest cost for the trucks (TL)
I_T: Investment cost of the truck (TL)
DT_T: Depreciation time of a truck (year)
Wd_T: Number of working days of the truck (day)
dr: Discount rate
n_T: Number of trucks

5.7 Module 6: Packing Cost Module

Appearance of the module is as shown in Figure 5.9. This module is designed to calculate the packing cost of coal. Packing plants available for Turkish Coal Enterprises and their specifications are listed in Appendix A. The user selects one of

the given packing plants. The variables about plant working condition like plant efficiency, number of shifts per day and shift duration is specified by the user.

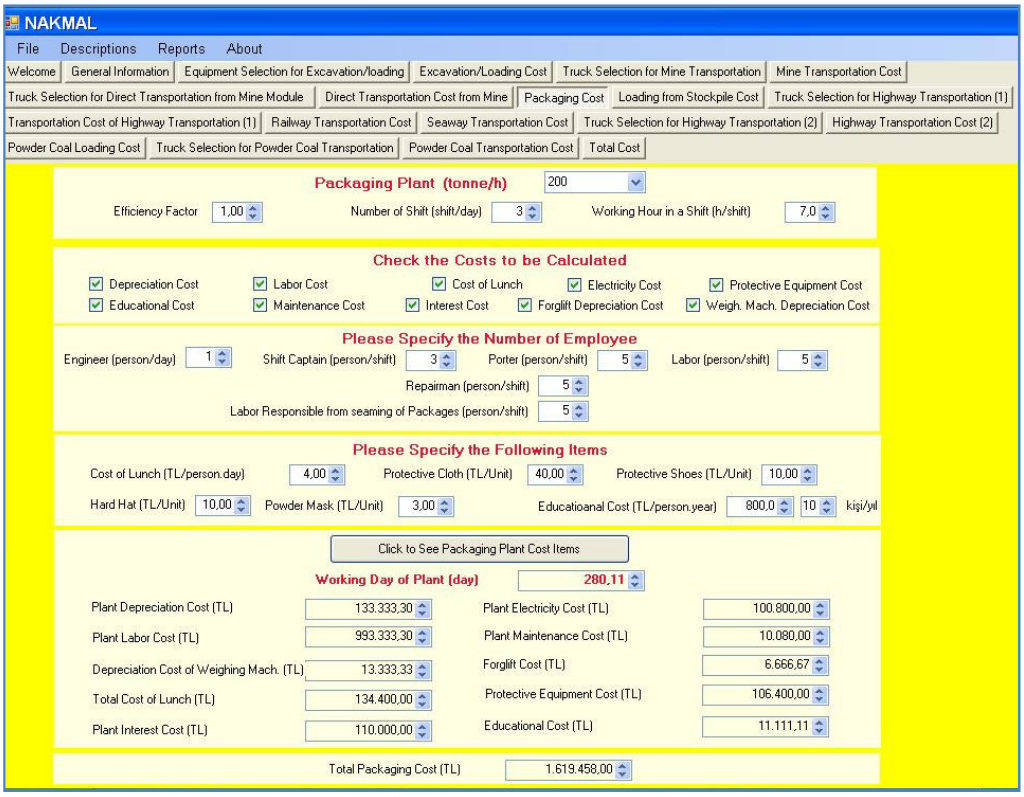

Figure 5.9 Appearance of *Packing Cost* module.

The code can compute the costs listed below.

- Depreciation cost
- Labor cost
- Electricity cost
- Repair and maintenance cost
- Interest cost
- Forklift cost
- Balancing Machine cost
- Training cost

- Food cost
- Protective equipment COST

The user specifies the required number of labors worked during packing process. The types of labor are as follows:

- Engineer
- Shift master
- Repairman
- Person responsible from packing
- Person responsible from package seaming
- Person responsible from loading of packages

The parameters related to protective equipment, cost of lunch and cost of education should be defined.

5.7.1 Working Hour Calculations for Packing Plant

The time needed to pack required amount of coal is calculated using equation 5.22.

$$\mathrm{Wh_P} = \frac{\mathrm{P_d}}{\mathrm{Cp_P}} \tag{5.22}$$

where,

Wh_P: Number of working hours of plant (hr)

P_d: Amount of coal demanded (tonne)

Cp_P: Capacity of the packing plant (tonne/hr)

Then working day of plant is computed by equation 5.23.

$$Wd_P = \frac{Wh_P}{n_S * H} \tag{5.23}$$

where,

Wd_P: Number of plant working days (days)

Wh_P: Number of working hours of plant (hr)

n_S: Number of shifts in a day

H: Number of hours in a shift (hr/shift)

5.7.2 Depreciation Cost of Packing Plant

Depreciation cost is calculated using equation 5.24 and salvage value is assumed to be 20% of plant cost (Karpuz *et al.*, 2008).

$$DC_P = \frac{I_P}{DT_P * 360} * sc * Wd_P \tag{5.24}$$

where,

DC_P: Depreciation cost of packing plant (TL)

I_P: Investment cost of packing plant (TL)

DT_P: Depreciation time of packing plant (years)

Wd_P: Number of plant working days (days)

sc: Salvage value coefficient

5.7.3 Labor Cost in Packing of Coal

The labor cost value is computed using equation 5.25.

$$LC_P = \sum_k n_k * S_k * \frac{Wd_P}{30} \tag{5.25}$$

where,

k: Types of plant labors index

n_k: Number of k^{th} type labors

S_k: Salary of k^{th} typr labor (TL)

Wd_P: Number of plant working days (days)

5.7.4 Electricity Cost of Packing Plant

Unit electricity cost is defined in database. The electricity consumption of each plant is given in Packing Plant Description Table in Appendix A. Electricity cost is then calculated by the following equation 5.26.

$$E_P = UEP * Cn_P * Wh_P \tag{5.26}$$

where,

E_P: Electricity cost in packing plant (TL)

UEP: Unit cost of electricity (TL/kW.hr)

Cn_P: Electricity consumption rate in packing plant (kW/hr)

Wh_P: Number of working hours of plant (hr)

5.7.5 Repair and Maintenance Cost of Packing Plant

Repair and maintenance cost of the plant is approximated as 10% of electricity cost.

5.7.6 Interest Cost of Packing Plant

The interest rate is assumed to be 12%. It is computed by equation 5.27 (Karpuz *et al.*, 2008).

$$IC_P = I_P * \frac{DT_P + 1}{2 * DT_P} * dr * \frac{Wd_P}{360} \quad (5\ 27)$$

where;

IC_P: Interest cost for packing plant (TL)

I_P: Investment cost of packing plant (TL)

DT_P: Depreciation time of packing plant (years)

dr: Discount rate

Wd_P: Number of working days of packing plant (days)

5.7.7 Depreciation Cost of Forklift in the Packing Plant

It is calculated by equation 5.28 (Karpuz *et al.*, 2008). Salvage value is assumed to be 20% of investment cost of the forklift.

$$DC_F = \frac{I_F}{DT_F * 360} * Wd_P * sc \quad (5.28)$$

Where,

DC_F: Depreciation cost of forklift (TL)

DT_F: Depreciation time of forklift (years)

I_F: Investment cost of forklift (TL)

Wd_P: Number of working days of plant (days)

sc: Salvage value coefficient

5.7.8 Depreciation Cost of Balancing Machine in the Packing Plant

It is calculated using equation 5.29 (Karpuz *et al.*, 2008). Salvage value is assumed to be 20% of investment cost of the balancing machine.

$$DC_B = \frac{I_B}{DT_B * 360} * Wd_P * sc \tag{5.29}$$

where,

DC_B: Depreciation cost of balancing machine (TL)

DT_B: Depreciation time of balancing machine (years)

I_B: Investment cost of balancing machine (TL)

Wd_P: Number of working days of plant (days)

sc: Salvage value coefficient

5.7.9 Labor Training Cost

The number of labors participate education and the yearly education cost per labor is defined by the user. The yearly educational cost of labors is then reflected by equation 5.30.

$$TC_P = n_P * \frac{UTC}{360} * Wd_P \tag{5.30}$$

where,

TC_P: Labor training cost in packing plant(TL)

n_P: Number of labors working in the packing plant

UTC: Yearly training cost per labor (TL)

Wd_P: Number of working days of plant (days)

5.7.10 Food Cost in the Packing Plant

It is the cost of lunch during packing process and is computed using equation 5.31.

$$CL_P = n_P * UCL * Wd_P \tag{5.31}$$

where,

CL_P: Cost of lunch for labors working in the packing plant (TL)

n_P: Number of labors working in the packing plant

UCL: Food cost per labor (TL/labor.day)

Wd_P: Number of plant working days (days)

5.7.11 Cost of Protective Equipment

Types of protective equipment used during packing process are listed below.

- Dust Protective
- Protective shoes
- Protective cap hat
- Protective clothes

It is assumed that dust protectives are consumed daily and other protective equipments are renewed yearly. The unit costs of these protective equipment are defined by the user and the overall cost through the project is computed using equation 5.32.

$$PC_P = (pm + \frac{(hh + pc + ps)}{360}) * n_P * Wd_P \tag{5.32}$$

where,

PC_P: Protective equipment cost (TL)

pm: Cost of unit dust protective (TL)

hh: Cost of unit cap hat (TL)

pc: Cost of unit protective clothes (TL)

ps: Cost of unit protective shoes (TL)

n_P: Number of labors working in the plant

Wd_P: Number of working days of packing plant (days)

5.8 Module 7: Cost of Loading from Stockpile

This module is used to calculate cost of loading of coal from stockpile. Appearance of the module window is as shown in Figure 5.10.

The items defined by the user are:

- The loader bucket capacity
- Number of loaders
- Fill factor
- Efficiency factor,
- Number of shifts
- Shift duration.

The items computed by the software in this module are:

- Number of working days of loader
- Number of total working hours
- Hourly output of loader

There is an informative window displaying shift duration for number of shifts 1, 2 and 3 to extend the packing duration over project duration.

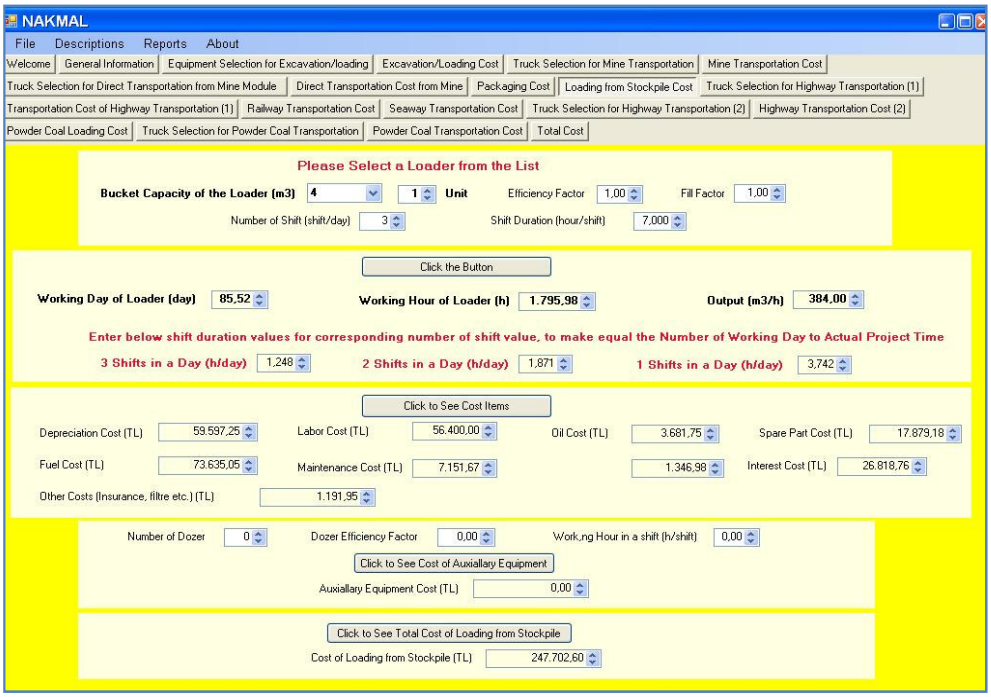

Figure 5.10 Appearance of *Cost of Loading from Stockpile* Module

5.8.1 Hourly Output of Loader

The hourly total output of the loader is computed using equation 5.2.

5.8.2 The Number of Working Days for Loader

The number of days that loader can complete the task is computed using equation 5.33.

$$Wd_L = \frac{P_d}{Q} * \frac{1}{n_S * H * d} \tag{5.33}$$

where,

Wd_L: Number of working days for loader (days)

P_d: Amount of coal demanded (tonne)

d: Density of the coal (tonne/m3)

Q: Hourly production in place (m^3/hr)

n_S: Number of shifts in a day

H: Shift duration in a shift (hr)

5.8.3 Cost of Loading in Stockpile

The items in loading costs of powder coal is depreciation cost, labor cost, fuel cost, oil cost, tire cost, repair and maintenance cost, spare parts cost, interest cost and unexpected cost in the title of other cost which is assumed to be 2% of depreciation cost. They all are calculated as in Module 2.

5.9 Module 8: Equipment Selection for Highway Transportation I

Appearance of the module window is as shown in Figure 5.11. Although a formulation for speed of a truck for both loaded and empty state is developed, a constant speed is assumed for highway transportation, since it is difficult for the user to enter the grade, length and road type information for all segments of the road. The average speed is assumed for an empty truck is 70 km/hr and for a loaded truck is 50 km/hr. The truck loading capacities are limited to 20 tonne trucks due to Turkish Highway Standards. This truck selection module is designed to transport the coal from packing plant or stockpile to the railroad station, port or the end point.

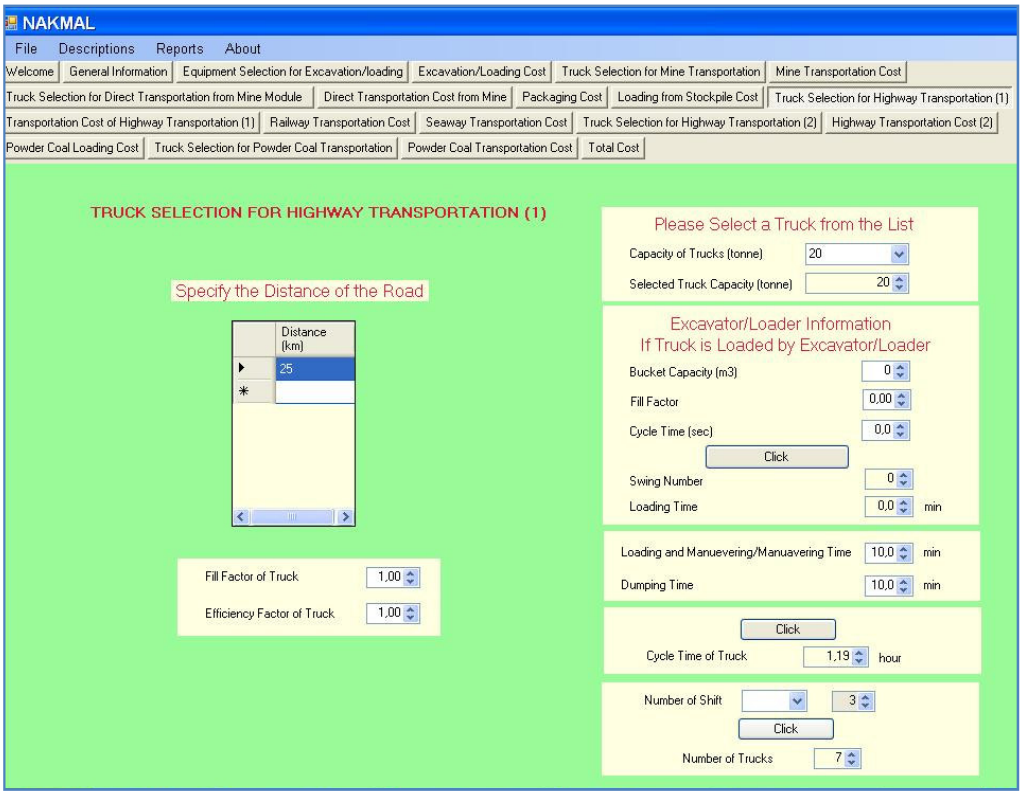

Figure 5.11 Appearance of *Truck Selection for Highway Transportation I* module

5.9.1 Cycle Time Calculation for Trucks

Fill factor, efficiency factor and the truck capacity for the truck is defined by the user. The user either enter the loading time information or define the specifications like bucket capacity, cycle time and fill factor of the loader to be able to compute the loading time. Dumping and maneuvering time information is defined by the user. The table time is computed dividing distance to average speed of the truck. Cycle time of the truck is calculated according to equation 5.10.

5.9.2 Number of Trucks Calculation

The necessary number of trucks is either computed according to packing plant capacity or the project time is taken as the constraint. If packing power plant option is selected. The number of shifts that trucks will be worked in a day is determined by the user by means of a combo box. The shift durations are assumed to be 7 hours for a shift. The hourly output of a truck is then calculated according to equation 5.14.

Then the number of trucks needed is computed using equation 5.34. The result is rounded to next bigger integer number if the decimal part is equal or greater than 25.

$$n_T = \frac{Cp_P}{Pr_T} \tag{5.34}$$

where,

n_T: Number of trucks

Cp_P: Capacity of the packing plant (tonne/hr)

Pr_T: Productivity of the truck (tonne/hr)

5.10 Module 9: Cost of Highway Transportation I

Appearance of the module is as shown in Figure 5.12.

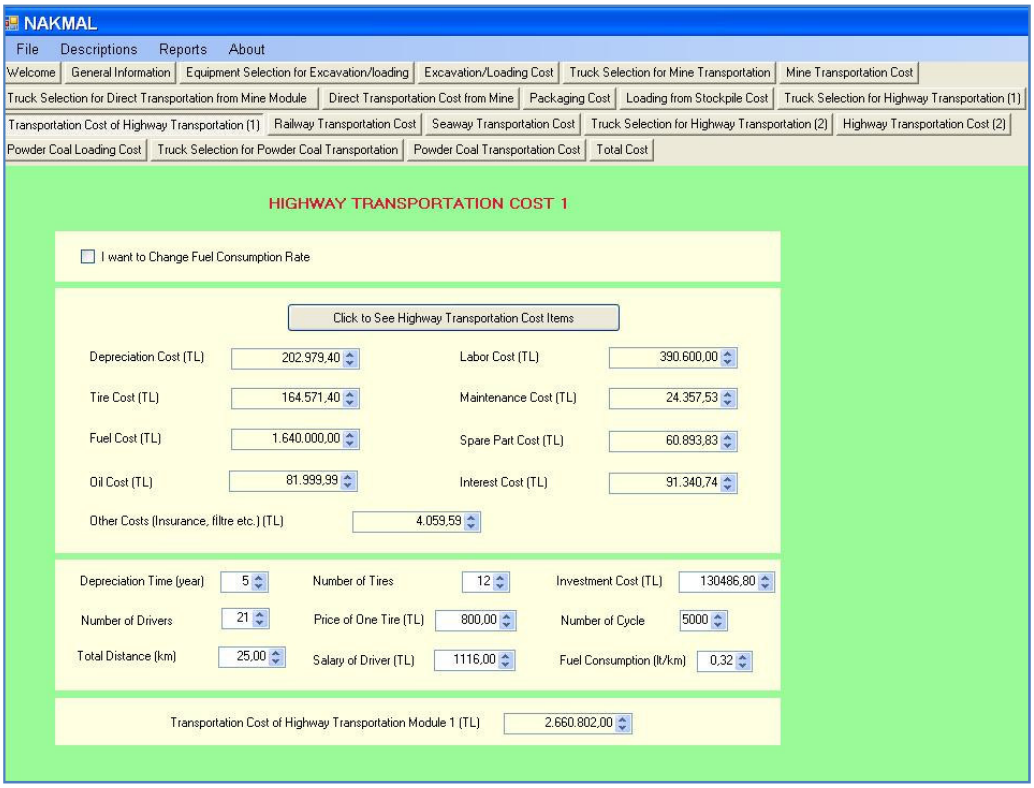

Figure 5.12 Appearance of *Cost of Highway Transportation I* module

Some unexpected small costs are considered in other costs item which is 2% of depreciation cost. In highway transportation module the consumption rate is assumed to be 0.32 lt/km for trucks. Although a consumption rate is defined, the user can change the value by a check box. Another difference of this module is the tire life. Tire life is assumed to be 2500 hours due to better road conditions in highways. All operating cost calculations are as in Module 5.

5.11 Module 10: Railway Transportation Cost

This module is designed to calculate loading cost to wagons at the first station, transporting cost and unloading cost of wagons at final station. Appearance of the module is as shown in Figure 5.13.

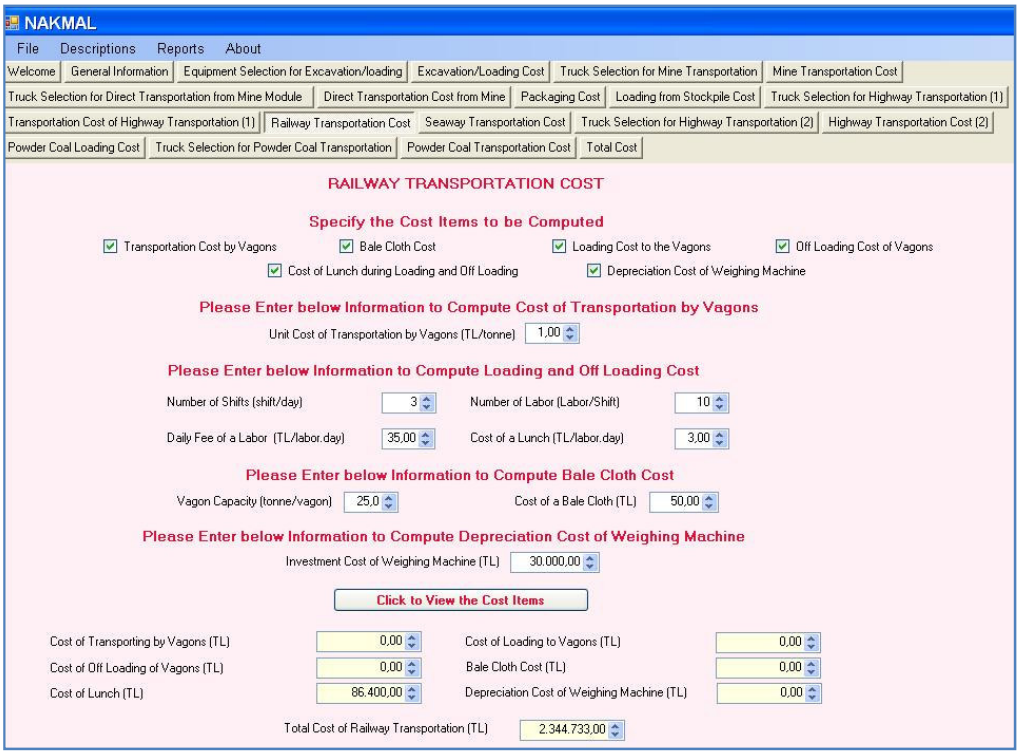

Figure 5.13 Appearance of *Railway Transportation Cost* module.

The cost items considered in this module are as follows and user determines the cost items to be computed by the checkboxes.

- Railroad transportation cost
- Bale cloth cost
- Cost of loading and unloading of the wagons
- Cost of lunch for workers loading or unloading wagons
- Cost of electronic balancing equipment

5.11.1 Transportation Cost by Wagons

This item covers the cost only transporting the coal by the wagons. To be able to compute this cost, the unit cost of transportation per tonne of coal information is defined and the cost is calculated using equation 5.35.

$$TC_R = UCT * P_d \tag{5.35}$$

where,

TC_R: Transportation cost by wagons (TL)

UCT: Unit cost of railway transportation (TL/tonne)

P_d: Amount of coal demanded (tonne)

5.11.2 Cover Cloth Cost of Wagons

The coal loaded to wagons has to be covered by using bale clothes according to railway legislation in Turkey. The cover cloth cost is assumed to be 10% of cover clothes price (Karpuz *et al.*, 2008). Then the cost is calculated using the following equation 5.36.

$$C_R = rr * \frac{P_d}{Cp_W} * UPB \tag{5.36}$$

where,

C_R: Cover cloth cost (TL)

P_d: Amount of coal demanded (tonne)

Cp_W: Wagon capacity of the train (tonne)

UPB: Price of a cover clothe (TL)

rr: Cover cloth cost coefficient

5.11.3 Cost of Loading/Unloading of Wagons

Calculating the labor cost in loading and unloading, the number of labors in a shift, the number of shifts that workers will work and daily wage of worker information is

defined by the user. Then the loading or unloading cost is calculated using equation 5.37.

$$LC_R = n_S * n_R * ww \tag{5.37}$$

where,

LC_R: Labor cost (TL)

n_S: Number of shifts in a day

n_R: Number of labors working to load/unload the wagons in a shift

ww: Daily wages of a labor (TL/labor.day)

5.11.4 Food Cost during Loading/Unloading of Wagons

The total number of labors and the cost of a lunch for a labor information is used to compute the cost of lunch. The equation 5.38 is used to compute cost of lunch.

$$CL_R = n_S * n_R * UCL \tag{5.38}$$

where,

CL_R: Food Cost (TL)

n_S: Number of shifts in a day

n_R: Number of labors working to load/unload the wagons in a shift

UCL: Food cost per labor (TL/labor.day)

5.11.5 Depreciation Cost of Balancing Machine

It is calculated as in equation 5.29. The only difference is that number of working days of the balancing machine during railway transportation is taken instead of packing.

5.12 Module 11: Cost of Transportation by Ship

This module is used to calculate the cost of transportation if the demanded coal is transported by using freight ships. Appearance of the module is as shown in Figure 5.14.

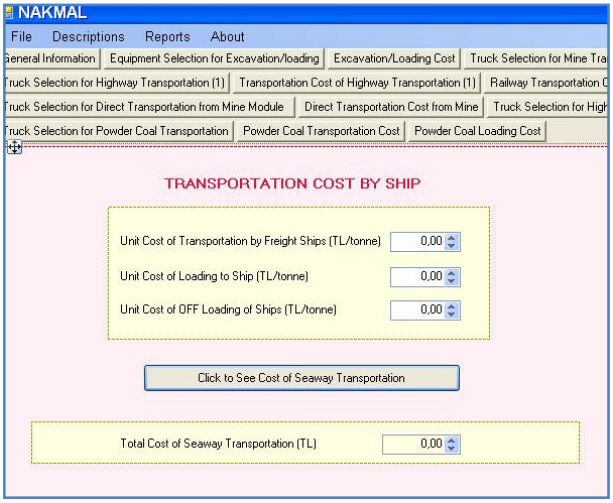

Figure 5.14 Appearance of *Transportation by ship* module.

The user enters unit loading cost of coal to the ship, the unit transportation cost by ship and unit discharging cost from the ship.

Total cost is calculated using equation 5.39.

$$TC_S = (uc_l + uc_t + uc_d) * P_d \tag{5.39}$$

where,

TC_S: Cost of transportation by ship (TL)

uc_l: Unit cost of loading (TL/tonne)

uc_t: Unit cost of transportation (TL/tonne)

uc_d: Unit cost of unloading (TL/tonne)

P_d: Amount of coal demanded (tonne)

5.13 Module 12: Truck Selection for Highway Transportation II

This module is used to complete the path after railway station or port. The appearance of the module is as shown in Figure 5.15. The basic difference from Module 4 is that transportation of coal task is completed in project duration in this module. The number of trucks necessary to complete the task in time is found by dividing necessary hourly output to truck hourly output. Input parameters and outputs of the module are as in Module 4.

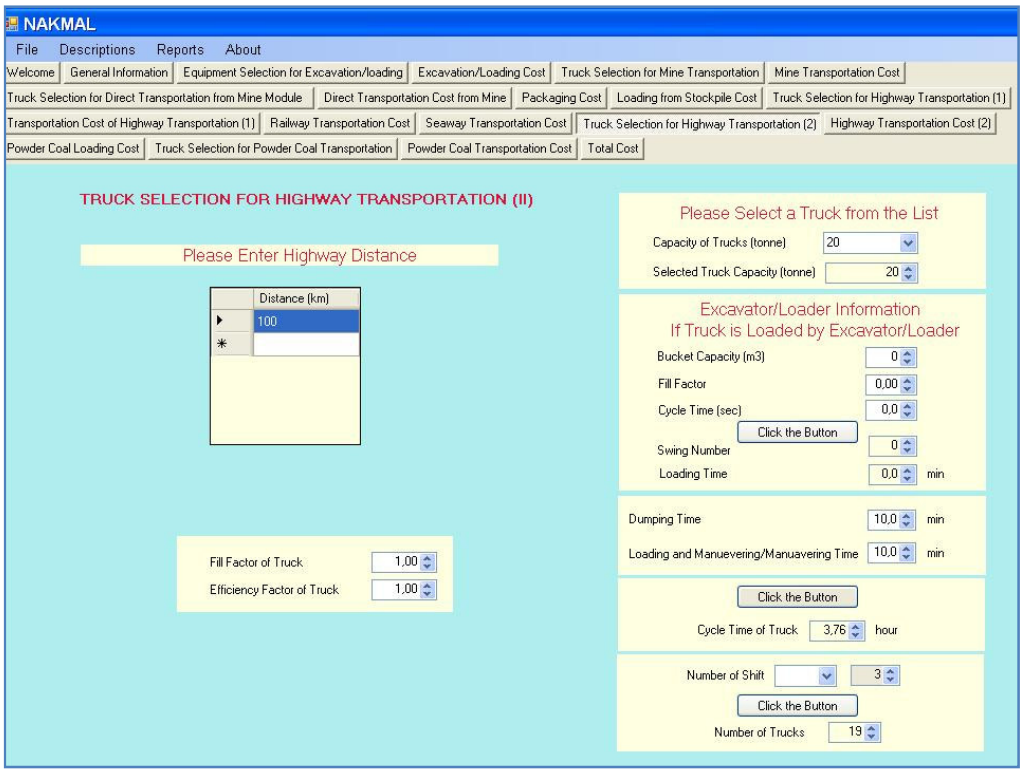

Figure 5.15 Appearance of *Truck Selection for Highway Transportation II* module

5.14 Module 13: Cost of Highway Transportation II

This module is designed to compute cost of transportation for the trucks specified in Module 12. Appearance of the module is as shown in Figure 5.16. The cost items are as in Module 2 and computed in the same manner.

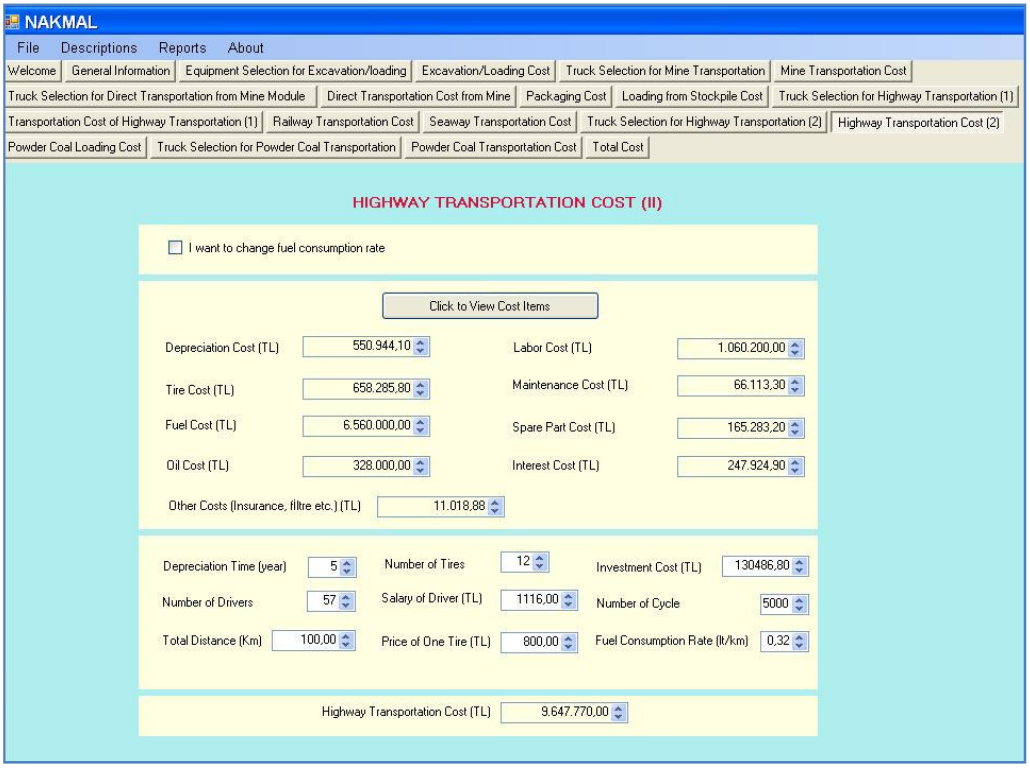

Figure 5.16 Appearance of *Cost of Highway Transportation II* module.

5.15 Module 14: Truck Selection for Direct Transportation from Mine

This module is used if the produced coal is directly transported from mine to a railway station or to a port or to a final destination point. Appearance of the module is as shown in Figure 5.17. Both road segments and highway segments are included in this module. This module is a mix of Module 4 and Module 8. The principle

through mine segments is as in Module 4 and the principle through highway segments is as in Module 8.

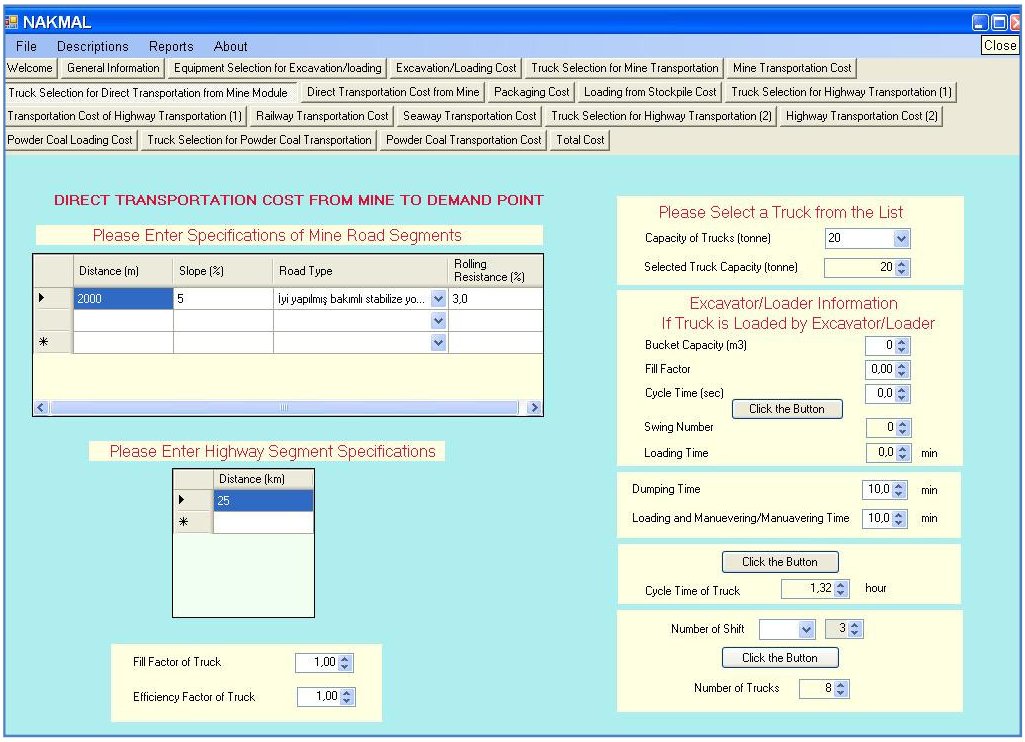

Figure 5.17 Appearance of *Truck Selection for Direct Transportation from Mine* module.

Inputs and outputs of the module is the same of Module 4 or Module 8. While calculating cycle time of a truck, the speed of the truck along mine segments are computed according to the graph in Figure 5.7, on the other hand average speed is assumed through highway segments for both loaded and empty state. The average speed is 70 km/hr for empty truck condition and 50 km/hr for loaded truck condition.

In calculating number of trucks, the hourly output of excavator/loader is divided to hourly output of truck as in equation 5.16.

5.16 Module 15: Cost of Direct Transportation from Mine

The cost items calculated in this module are the same in other transportation cost modules. The appearance of the Module is as in Figure 5.18.

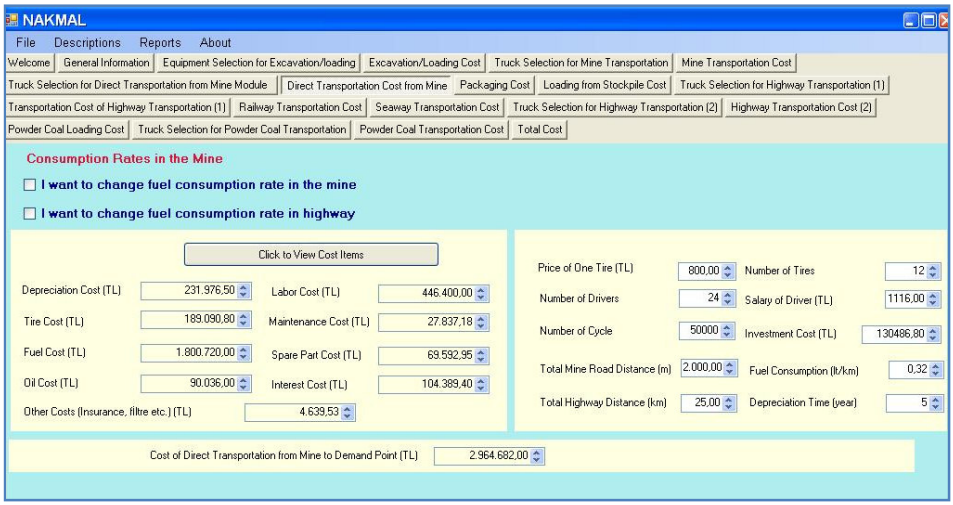

Figure 5.18 Appearance of *Cost of Direct Transportation from Mine* module.

The cost calculations are as in Module 2 except fuel cost and tire cost. The fuel consumption through mine roads is decided according to *Fuel Consumption in the Mine* Table in Appendix A, whereas the fuel consumption through highway segments is assumed to be 0.32 lt/km. Overall fuel consumption is computed using equation 5.40.

$$FC_D = \sum_l UCF * D_l * C_l \tag{5.40}$$

where,

l: Road type index (highway, mine road)

FC_D: Fuel cost of trucks if both mine road segments and highway segments are present (TL)

UCF: Unit cost of fuel (TL/lt)

D_l: Distance travelled for l^{th} type road (km)

Cn_l: Consumption rate for l^{th} type road (lt/km)

Similarly, in tire cost calculation the tire life is 2500 hours for highway segments and 2000 hours for mine road segments. Then overall tire cost is computed using following Equation 5.41.

$$TC_D = \sum_l \frac{UPT * nt_T * Wh_l}{TL_l} \tag{5.41}$$

where,

l: Road type index (highway, mine road)

TC_D: Tire cost of trucks if both mine road segments and highway segments are present (TL)

UPT: Unit price of a truck tire (TL)

nt_T: Number of tires of the truck

Wh_l: Number of working hours through l^{th} type road (hr)

TL_l: Tire life for l^{th} type road (hours)

5.17 Module 16: Powder Coal Loading Cost

This module is used if powder coal transportation is applied after packing process. Appearance of the module is as shown in Figure 5.19. The powder coal separated during packing plant is loaded to trucks. During loading process rubber tired loaders are used. The list of loaders and their specifications are given in Appendix A.

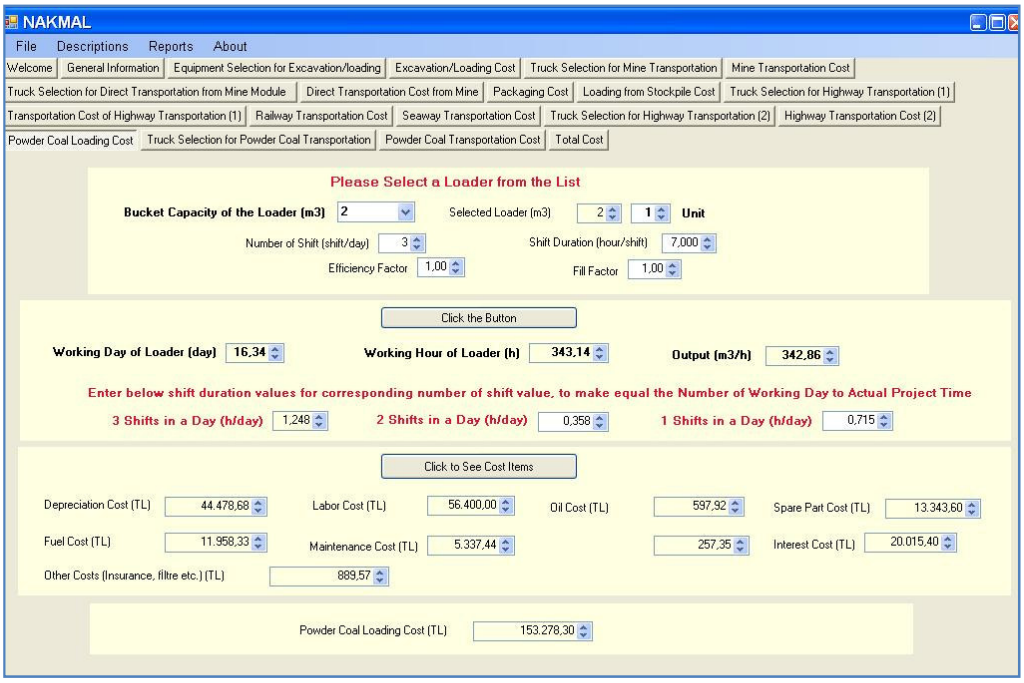

Figure 5.19 Appearance of *Powder Coal Loading Cost* module.

The loader bucket capacity, fill factor, efficiency factor and the number of loaders is defined by the user. The time needed to load the powder coal in daily basis, the total loader working hour and total hourly output of the loader in defined condition is computed. In an information window, the necessary shift durations for different number of shifts to scatter the loading process over actual project duration is given.

5.17.1 Hourly Output of Loader and Number of Working Days Calculations

Hourly output of a loader can be computed through equation 5.2. The number of days that loader can complete the task is computed similar as in equation 5.33. The only difference is that the coal amount is replaced by powder coal amount.

5.17.2 Loading Cost Calculations

The items in loading costs of powder coal is depreciation cost, labor cost, fuel cost, oil cost, tire cost, repair and maintenance cost, spare parts cost, interest cost and other cost. Other cost item involves some small and unexpected costs and assumed to be 2% of depreciation cost. They all are calculated as in Module 2.

5.18 Module 17. Truck Selection for Powder Coal Transportation

This module is used to select a suitable truck for selected loader in Module 17. Appearance of the module is as shown in Figure 5.20. It is very similar to Module 14. The only difference is the transported amount. In this module the transported amount is 15% of produced coal. All input variables and outputs of the module is the same as in Module 14. Cycle time calculation for the truck is made in the same manner and number of trucks is calculated by dividing hourly output of selected loader in previous module to hourly output of the truck.

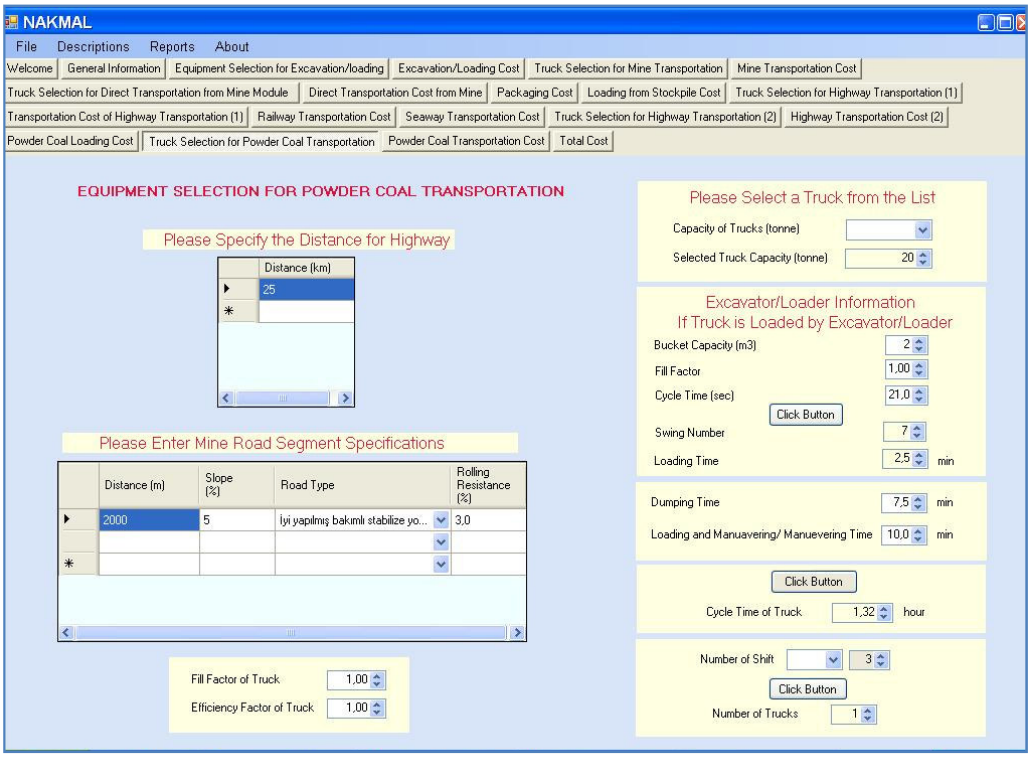

Figure 5.20 Appearance of *Truck Selection for Powder Coal Transportation* module.

5.19 Module 18. Powder Coal Transportation Cost

This module is run to compute cost of transportation for selected truck in previous module. Appearance of the module is as shown in Figure 5.21. Equations in Module 15 are used to compute the cost items. The consumption rates both mine road and highway segments set by the code can be changed by the user by clicking the related check boxes shown in Figure 5.21.

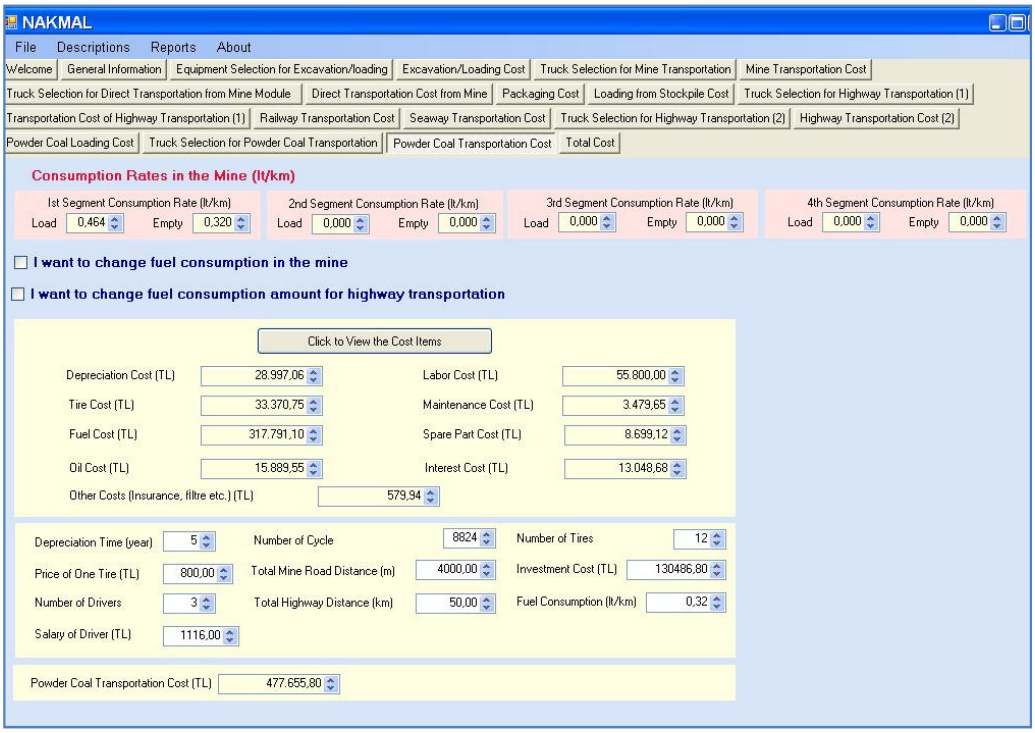

Figure 5.21 Appearance of *Powder Coal Transportation Cost* module.

5.20 Module 19: Total Cost Module

This model is run to compute sum of all cost items of defined work. According to selections in General Information Module, the displayed items change in Total Cost Module, i.e. only related cost items are displayed. Appearance of the module is as shown in Figure 5.22. Unit costs are computed simply by dividing the cost to the amount of coal. It should be noted that if packing is applied, the amount of coal transported before and after packing process change. The only input of the module is the profit rate, of contractor. If the work is awarded a contractor, the contractor's profit rate is defined. At the end, Final cost of work and final unit cost of work is displayed.

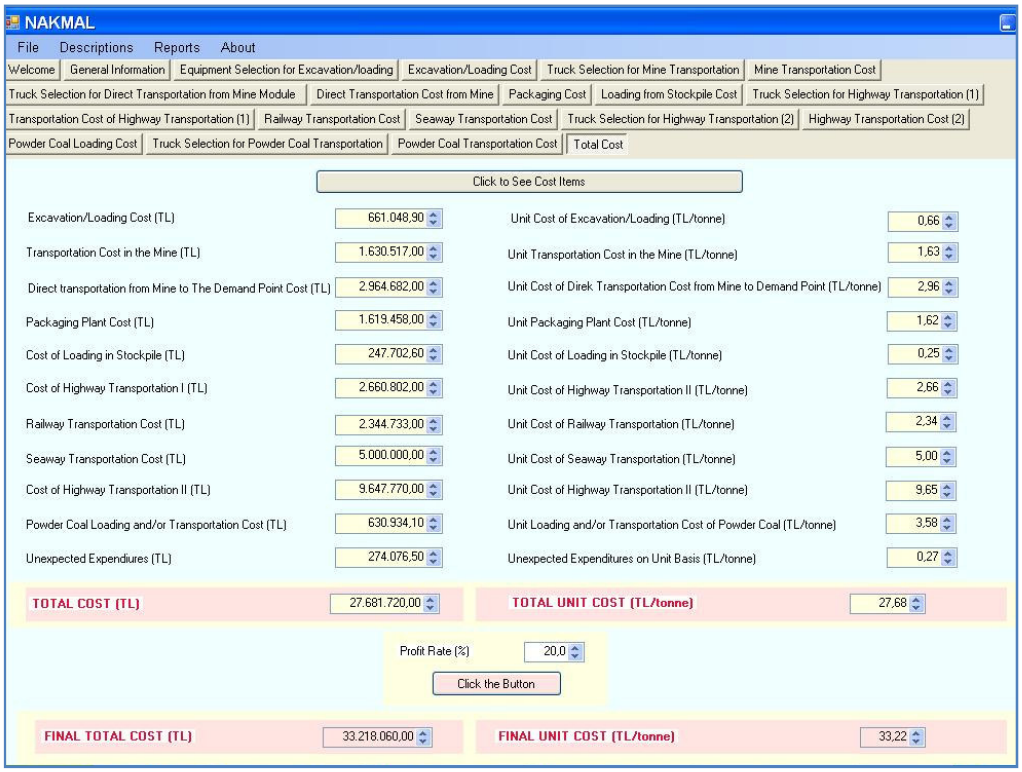

Figure 5.22 Appearance of *Total Cost Module*

CHAPTER 6

VALIDATION OF THE MODEL

The NAKMAL has been illustrated with the following example for the both dependent module algorithm and independent module algorithm. 180.000 tonne of packed coal is demanded by the Isparta city at a project period of 6 months through highway. Distance inside the mine to packing plant is 4 km. Distance from packing plant to destination point is 420 km. Average grade resistance of the mine road is 5 % and rolling and road type is graded mine road in wet condition.

6.1 Inputs of the Case

Inputs of General Information Module is given in Table 6.1.

Table 6.1 Inputs of General Information Module

Amount of coal: 180,000 tonne	Project duration: 180 days
Actual working duration: 150 days	Swell factor: 1.25
Density of coal: 1.45 tonne/m³	

Inputs of Excavator/Loader Selection Module is given in Table 6.2.

Table 6.2 Inputs of Excavator/Loader Selection Module

Depth of cut correction factor: 1	Angle of swing correction factor: 1
Efficiency factor: 1	Fill factor: 1
Bucket capacity: 3 m³	Number of excavators: 1

Inputs of Excavation/Loading Cost Module is given in Table 6.3. No auxiliary equipment is used in the sample problem and the number of personnels is as in Table 6.3.

Table 6.3 Inputs of Excavation/Loading Cost Module

Mine manager: 1	Engineer: 1
Formen: 1	Administrative personnel (each type): 1

Inputs of Truck Selection in Mine Transportation Module is given in Table 6.4.

Table 6.4 Inputs of Truck Selection in Mine Transportation Module

Distance: 4.000 m	Slope: 5 %
Rolling resistance: 7,5 %	Fill factor: 1
Efficiency factor: 1	Maneuvering and dumping time: 5 min
Number of shifts: 3	

Inputs of Packing Plant Module is given in Table 6.5.

Table 6.5 Inputs of Packing Plant Module

Plant capacity: 75 tonne/hr	Efficiency: 0.9
Number of shifts: 3	Shift durations: 7 hours
Number of engineers: 1 person/day	Number of shift captains: 1 person/shift
Number of porters: 5 person/shift	Number of workers: 3 person/shift
Number of repairmen: 3 person/shift	Price of a protective shoes: 10 TL
Price of a protective clothe: 40 TL	Price of a dust protective: 0.4 TL
Price of a cap hat: 10 TL	Number of persons trained: 6
Yearly training seminar cost: 500 TL/year	Yearly training seminar cost: 500 TL/year

Inputs of Truck Selection for Highway Transportation I Module is given in Table 6.6.

Table 6.6 Inputs of Truck Selection for Highway Transportation

Distance: 420 km	Fill factor: 1
Efficiency factor: 1	Maneuvering and dumping time: 45 min

6.2 Independent Module Solution

In the case of independent module algorithm solution, the result and interface of the modules, according to input data stated above, are given below in Figures 6.1-6.8 In independent module solution, all modules are run independently from each other and relation between the modules is not thought.

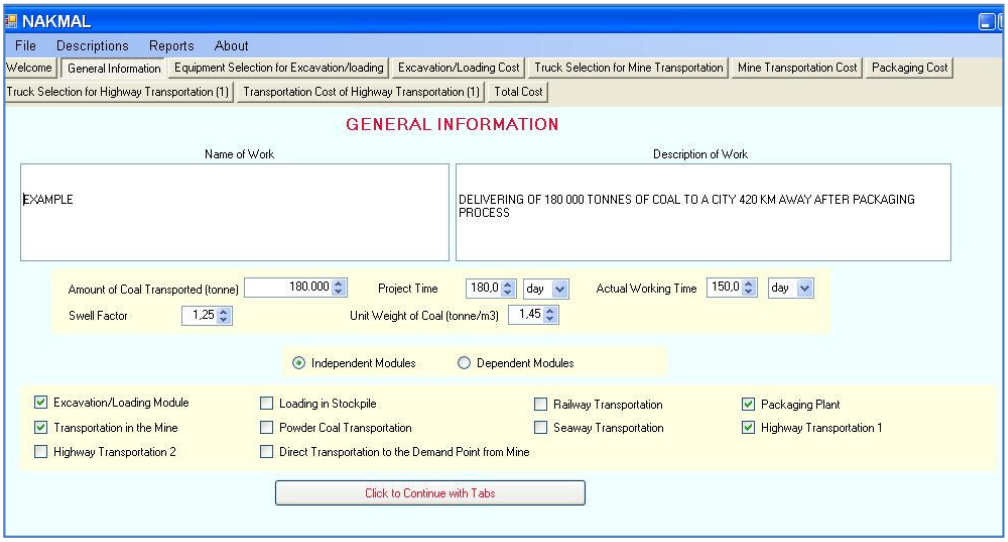

Figure 6.1 *General Information Module* interface in the case of independent module algorithm for the example.

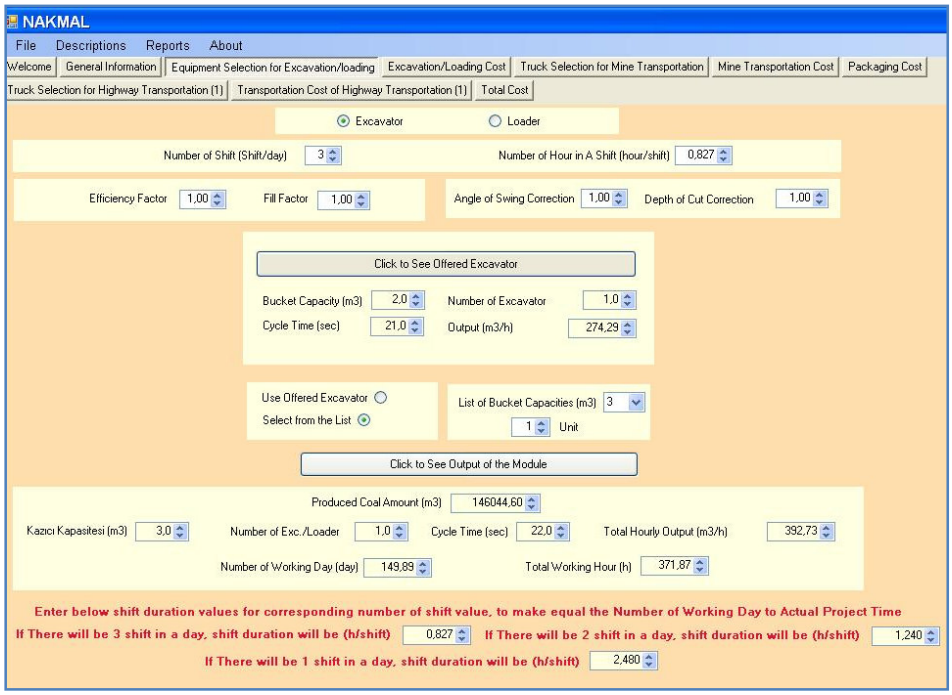

Figure 6.2 *Excavator/Loader Selection Module* interface in the case of independent module algorithm for the example.

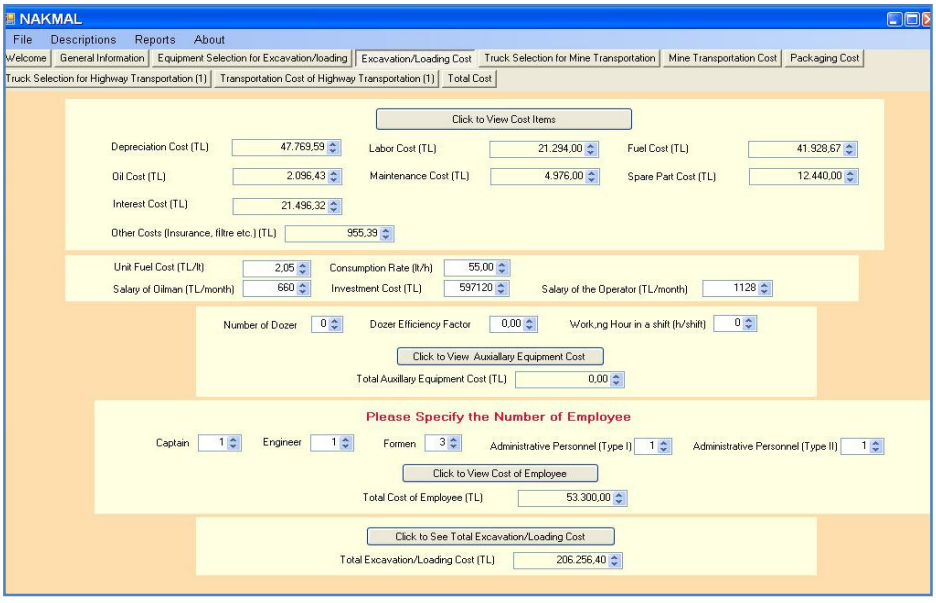

Figure 6.3 *Excavation/Loading Cost Module* interface in the case of independent module algorithm for the example.

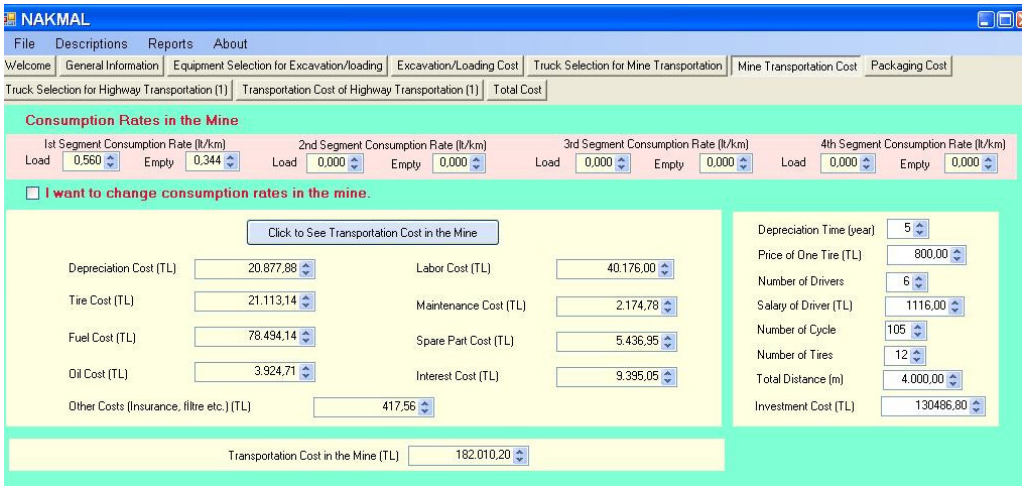

Figure 6.4 *Mine Transportation Cost Module* interface in the case of independent module algorithm for the example.

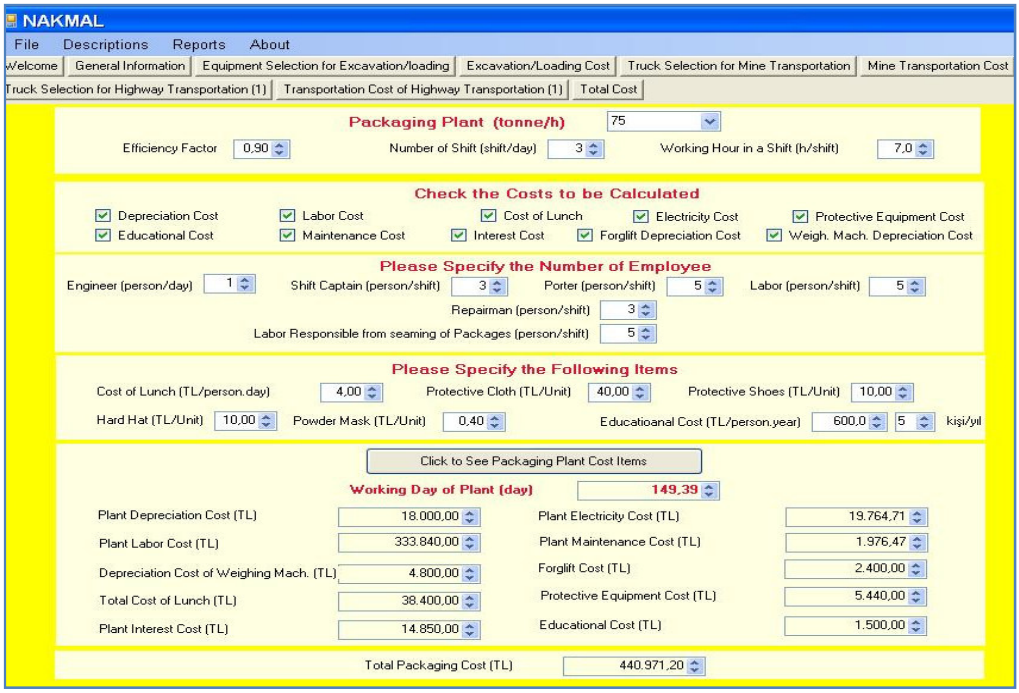

Figure 6.5 *Packing Cost Module* interface in the case of independent module algorithm for the example.

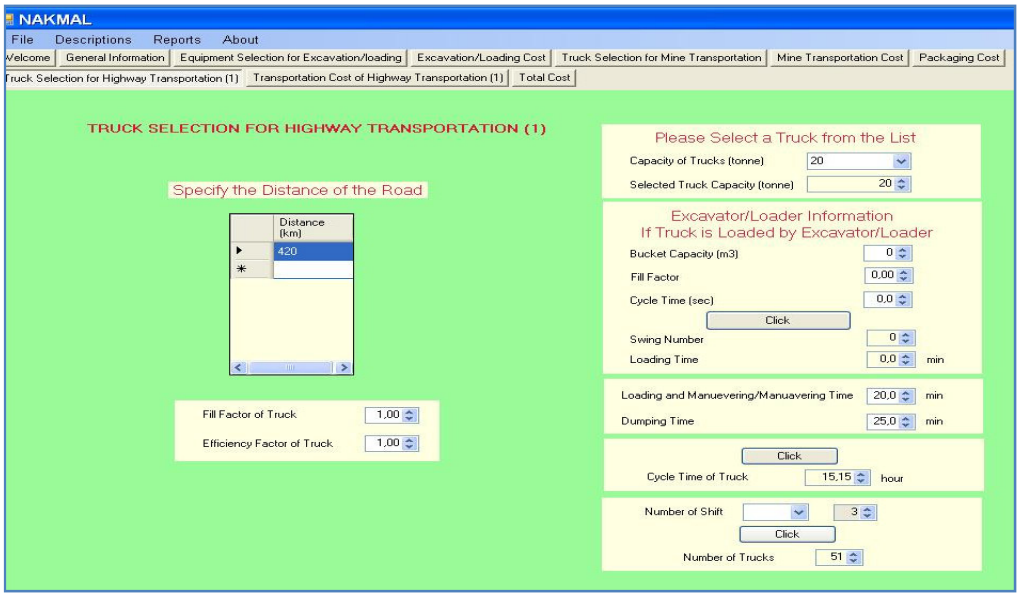

Figure 6.6 *Truck Selection for Highway Transportation I Module* interface in the case of independent module algorithm for the example.

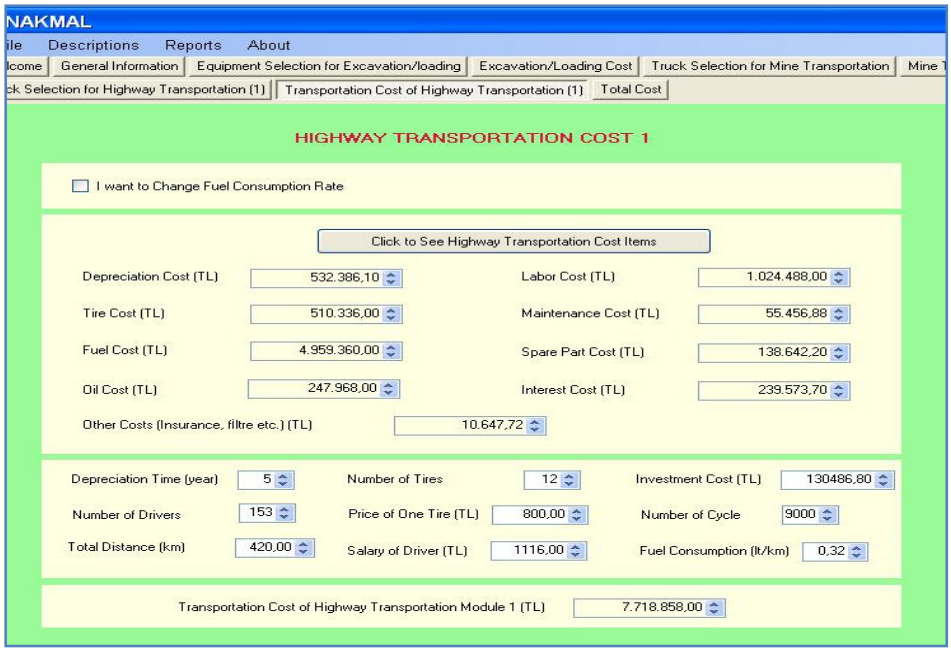

Figure 6.7 *Highway Transportation Cost I Module* interface in the case of independent module algorithm for the example.

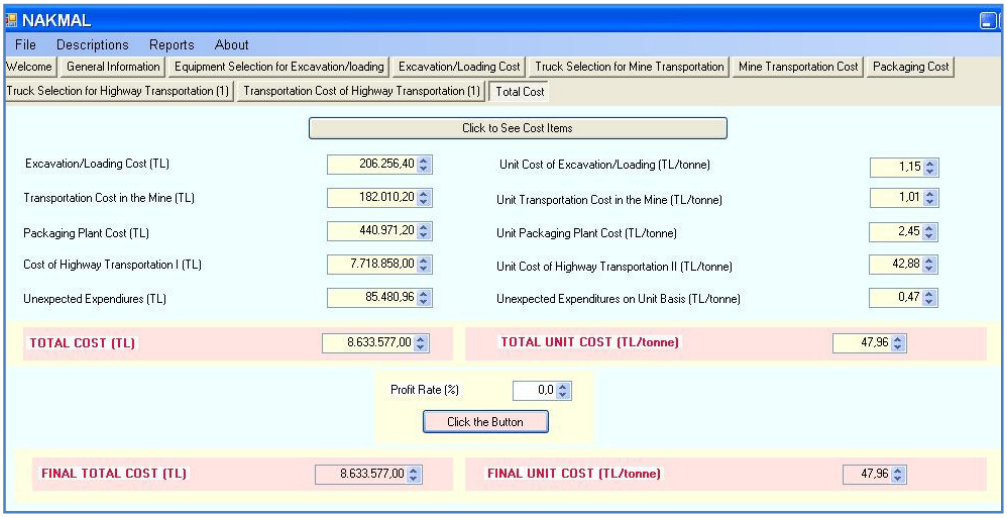

Figure 6.8 *Total Cost Module* interface in the case of independent module algorithm for the example.

6.3 Dependent Module Solution

In the case of dependent module solution, the result and interface of all modules, according to stated input data in section 6.1, are given below in Figures 6.9-6.16. In dependent module solution, all modules are run dependently and relation between the modules is taken into consideration.

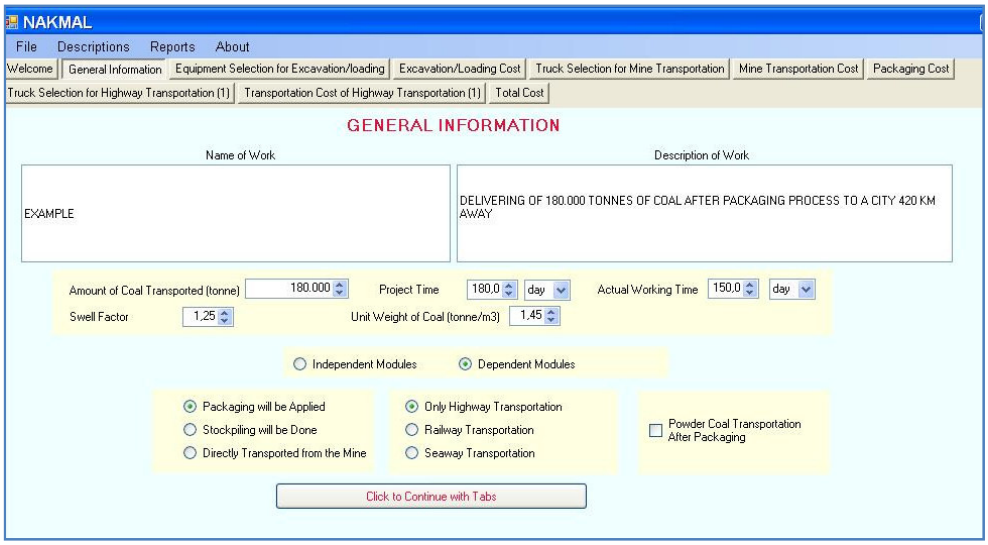

Figure 6.9 *General Information Module* interface in the case of dependent module algorithm for the example.

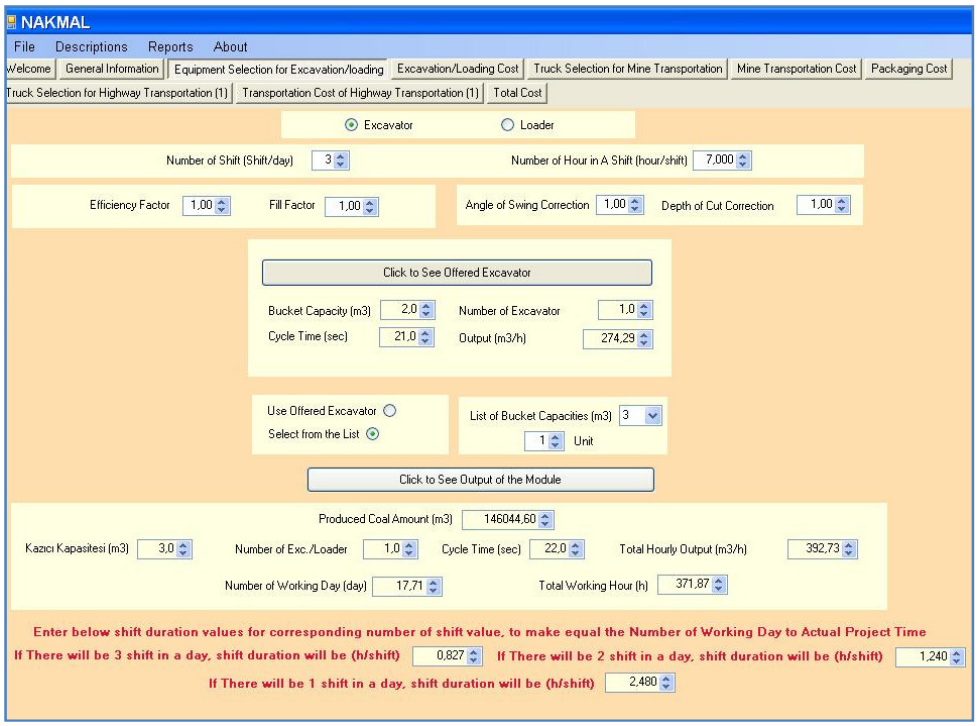

Figure 6.10 *Excavator/Loader Selection Module* interface in the case of dependent module algorithm for the example.

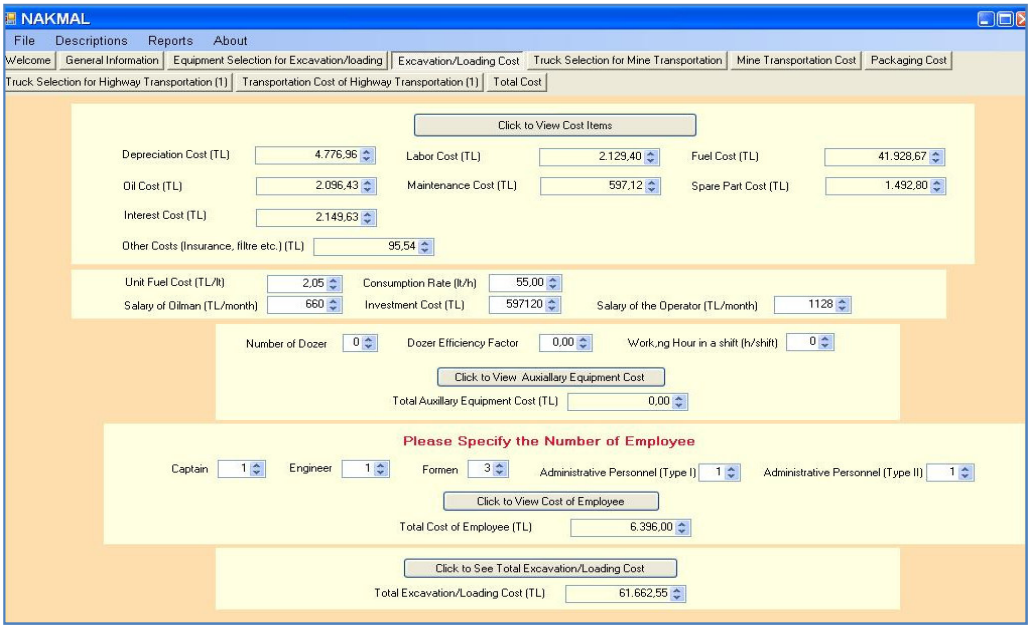

Figure 6.11 *Excavation/Loading Cost Module* interface in the case of dependent module algorithm for the example.

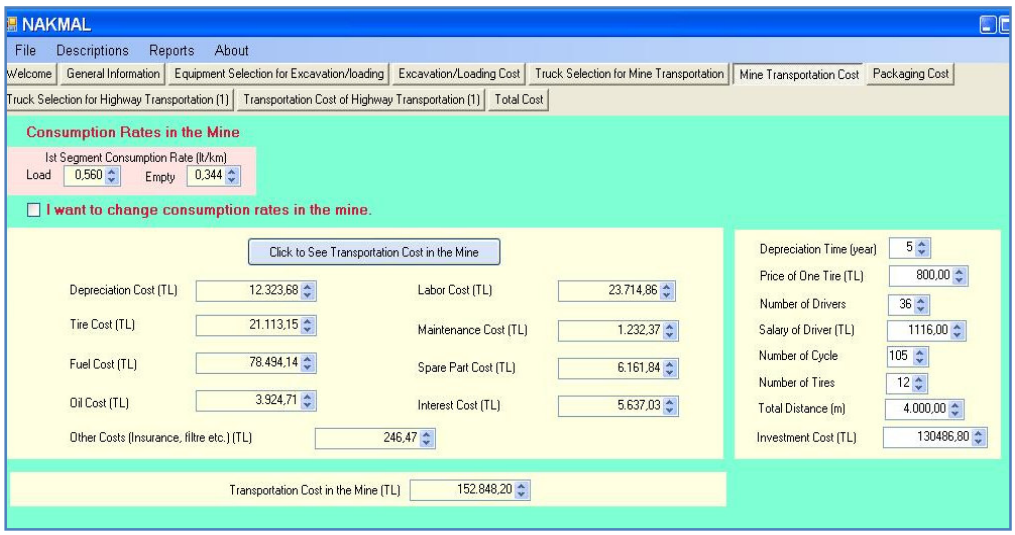

Figure 6.12 *Mine Transportation Cost Module* interface in the case of dependent module algorithm for the example.

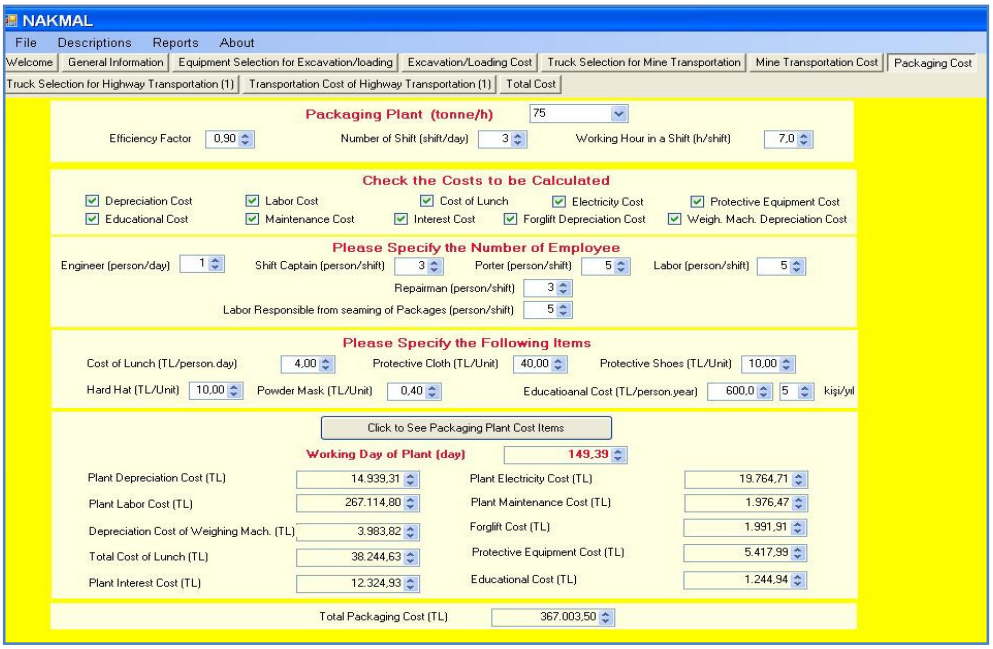

Figure 6.13 *Packing Cost Module* interface in the case of dependent module algorithm for the example.

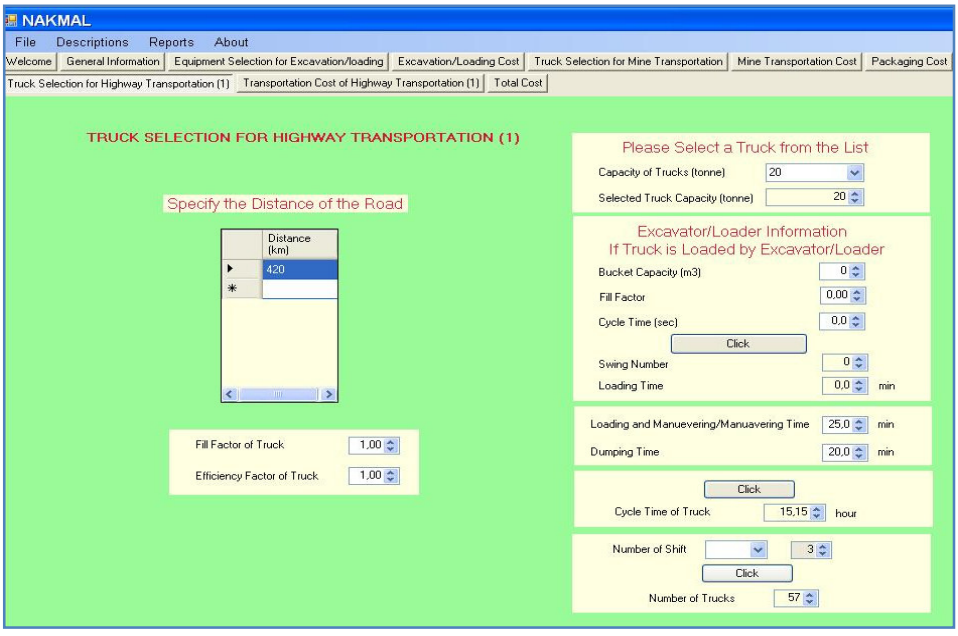

Figure 6.14 *Truck Selection for Highway Transportation I Module* interface in the case of dependent module algorithm for the example.

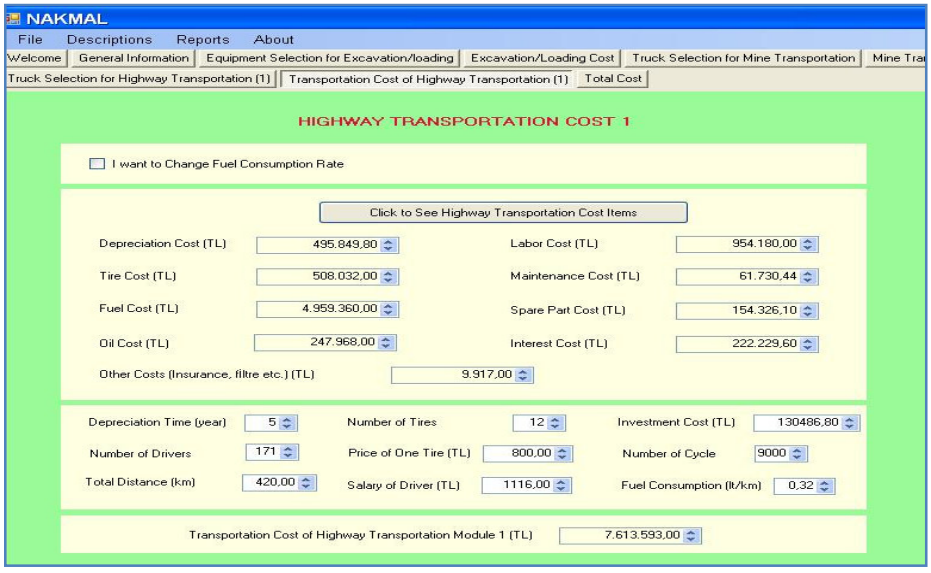

Figure 6.15 *Highway Transportation Cost I Module* interface in the case of dependent module algorithm for the example.

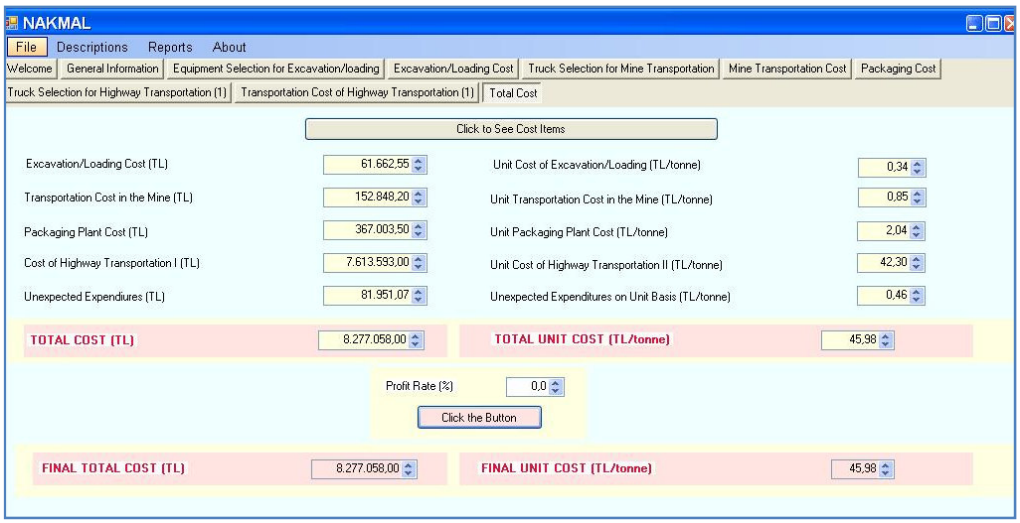

Figure 6.16 Total Cost Module interface in the case of dependent module algorithm for the example.

The computed results are summarized for the two algorithms as shown in Table 6.7 and Table 6.8 in terms of both total and unit costs. All cost items are lower for dependent module solution than independent module

solution as can be seen from Table 6.7 and 6.8. The difference is about 4,5 % and higher difference is obtained in the excavating cost.

Table 6.7 Summary of total costs in independent and dependent module algorithm.

Cost Items	Cost (TL) (Independent Modules)	Cost (TL) (Dependent Modules)
Excavation Loading Cost	206,256.40	61,662.55
Transportation Cost in the Mine	182,010.20	152,848.20
Packing Cost	440,971.20	367,003.50
Cost of Highway Transportation I	7,7718,058.00	7,613,593.00
Unexpected expenditures	85,480.96	81,951.07
TOTAL COST	8,663,577.00	8,277,058.00

Table 6.8 Summary of unit costs in independent and dependent module algorithm.

Cost Items	Unit Cost (TL/tonne) (Independent Modules)	Unit Cost (TL/tonne) (Dependent Modules)
Excavation Loading Cost	1.15	0.34
Transportation Cost in the Mine	1.01	0.85
Packing Cost	2.45	2.04
Cost of Highway Transportation I	42.88	42.30
Unexpected expenditures	0.47	0.46
TOTAL COST	47.96	45.98

The main reason of the difference between these two modules illustrated in sections 6.2 and 6.3 is due to the logic behind the algorithms. In the dependent module algorithm, all modules are dependent on each other and system works continuously and efficiently. Idle times for equipments are minimized and efficiency is high. In the independent module, subsystems works independently and number of working hours of equipments are extended to actual project duration. Hence, idle time for the equipments are high and efficiency of the system is low. Hence the total and unit cost in independent module algorithm is higher than that in dependent module algorithm.

6.4 Validation

The results of computed unit highway transportation cost for this sample problem is given in Table 6.8 and it is 42.88 TL/tonne for 420 km distance when fullness ratio of the truck is 1. The unit transportation costs of trucks for different fullness ratio values are given by Sahin *et al*. (2009) as shown in Figure 2.1. In Figure 2.1, if fullness ratio is taken as 1, 420 km that is the distance in the sample problem problem isdefined above, the unit transportation cost is approximately 30 $/tonne. The transportation cost is computed by NAKMAL is very close to that of Sahin *et al*. (2009). This implies that the transportation modules developed through this study is reliable.

A transportation cost problem studied by TKİ is solved in NAKMAL and it is seen that results are very close to each other. 5300 tonne of coal is transported from the face to a packing plant 9 km away from the face. The inputs of the problem is as given in Table 6.9. NAKMAL computes the transportation cost as 2.02 TL/tonne whereas the cost calculated by TKİ is 2.11 TL/tonne.

Table 6.9 Inputs of the transportation problem of TKİ.

Distance: 9000 m	Slope: 2 %
Rolling resistance: 2 %	Fill factor: 1
Efficiency factor: 1	Maneuvering and dumping time: 40 min
Number of shifts: 3	Amount of coal: 5300 tonne

NAKMAL total cost computation results are compatible with the recent studies and cost computations of TKİ. This implies that NAKMAL is a reliable software to calculate excavation/loading and transportation cost.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The goal of this study is to compute the total transportation cost of coal delivered from a mine to a destination point for different transportation alternatives, including material handling cost, stockpiling cost, packing cost and constituted powder coal transportation cost. For the above task, a model is developed and coded in Visual Studio.NET 2005 platform. The total transportation cost is computed through the code called NAKMAL. The alternatives in delivering of coal are defined and divided into subsystems.

NAKMAL makes computations with respect to two different algorithms. In the independent algorithm, the equipment selection procedure is performed to meet the project duration but in dependent algorithm, equipment selection is performed based on the output of previous subsystem. In the independent module, subsystems works independently and number of working hours of equipments are extended to actual project duration. Hence, idle times for the equipments are high and efficiency of the system is low. When the results of these algorithms compared to each other, it is seen that the results are lower for dependent model algorithm. Dependent module algorithm is modeled in a way that the relation between the successive subsystems are taken into consideration. Idle time for an equipment is minimized and number of equipments for a subsystem is specified with respect to the equipment productivity of previous subsystem. Hence, greater efficiency is achieved and cost is minimized with respect to dependent module algorithm.

The fixed and variable operating cost items mostly are based on the TKİ's long year's experience. Hence NAKMAL may also be utilized by other companies' related problems.

NAKMAL is an user friendly software and can be easily updated. An outsource database created in Microsoft Access makes updating process easy for the user.

NAKMAL is reliable, for example the NAKMAL output for highway segments is compared to the similar studies such as Sahin *et al*. (2009) and it is seen that the results are quite compatible with each other. NAKMAL provided 42,88 TL/tone for 420 km if fullness ratio of the truck is 1 while Sahin *et al*. (2009) computed the 30 $/tonne.

GIS can be utilized to better represent the physical characteristics of highway segments.

Optimization studies can be considered with respect to supply, demand and locations. Possible coal supply amounts and coal demands of cities may be used to create zones supplied by the TKİ coal mines.

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APPENDIX A

Table A.1 Excavator Descriptions.(Karpuz *et al*., 2008).

Bucket Capacity (m^3)	Cycle Time (sec)	Investment Cost (TL)	Fuel Cons. Rate (lt/hr)	Oil Cons. Rate (lt/hr)	Depreciation Time (years)
2	21	527,260.10	55	2.75	5
3	22	597,119.90	55	2.75	5
4	25	890,555.00	60	3.00	5
5	30	999,822.00	65	3.25	5
6	35	1,070,685.00	70	3.50	5
7	35	1,471,300.00	70	3.50	5

Table A.2 Loader descriptions (Karpuz *et al*., 2008).

Bucket Capacity (m^3)	Cycle Time (sec)	Investment Cost (TL)	Fuel Cons. Rate (lt/hr)	Tire Cost (TL)	Depreciation Time (years)
2	21	200,154.10	17	1500	5
3	30	254,753.30	19	1500	5
4	30	268,187.60	20	1500	5
5	33	403,104.20	23	2000	5
6	33	443,906.00	25	2000	5
7	33	695,000.00	27	2000	5

Table A.3 Truck descriptions (Karpuz *et al*., 2008).

Truck Capacity (tonne)	Investment Cost (TL)	Fuel Consumption Rate in Highways (lt/km)	Tire Cost (TL)	Depreciation Time (years)	Number of Tires
16	116865.2	0.32	800	5	10
17	120270.6	0.32	800	5	10
18	123676	0.32	800	5	10
19	127081.4	0.32	800	5	10
20	130486.8	0.32	800	5	12
21	133892.2	0.32	800	5	12
22	137297.6	0.32	800	5	12
23	140702.9	0.32	800	5	12
24	144108.3	0.32	800	5	12
25	147513.7	0.32	800	5	12
26	150919.1	0.32	800	5	14
27	154324.5	0.32	800	5	14
28	157729.9	0.32	800	5	14
29	161135.3	0.32	800	5	14
30	164540.7	0.32	800	5	14
31	167946.1	0.32	800	5	14
32	171351.5	0.32	800	5	14
33	174756.9	0.32	800	5	14
34	178162.3	0.32	800	5	14
35	181567.7	0.32	800	5	14
36	184973	0.32	800	5	14
37	188378.4	0.32	800	5	14
38	191783.8	0.32	800	5	14
39	195189.2	0.32	800	5	14
40	202000	0.32	800	5	14

Table A.4 Packing plant descriptions (Karpuz *et al*., 2008).

Plant Capacity (tonne/hr)	Invest. Cost (TL)	Depreciation Time of Plant (years)	Electricity Consump. Rate (KW/hr)	Price of Balancing Mach. (TL)	Depreciation Time of Balancing Mach. (years)
25	170,000	10	14.28	60,000	5
50	320,000	10	28.57	60,000	5
75	450,000	10	42.00	60,000	5
100	600,000	10	57.00	60,000	5
125	750,000	10	71.40	60,000	5
150	900,000	10	85.68	60,000	5
175	1,050,000	10	99.96	60,000	5
200	1,200,000	10	114.24	60,000	5
225	1,350,000	10	128.52	60,000	5
250	1,500,000	10	142.80	60,000	5

Table A.5 Rolling Resistance Descriptions (Karpuz *et al*., 2008).

Road Type	Rolling Resistance (%)
Asphalt (dry)	2.0
Asphalt (wet)	2.0
Gravel road (dry)	3.0
Gravel road (wet)	3.0
Graded mine road (dry)	5.0
Graded mine road (wet)	7.5

Table A.6 Auxiliary Equipment Description (Karpuz *et al*., 2008).

Definition	Fuel Consump. Rate (lt/hr)	Investment Cost (YTL)	Depreciation Time (years)
Dozer	20.0	450,000	5

Table A.7 Fuel consumption rate versus rolling resistance relation (Karpuz *et al*., 2008).

Rolling Resistance (%)	Fuel Consumption Rates in Mine Roads (lt/km)	Rolling Resistance (%)	Fuel Consumption Rates in Mine Roads (lt/km)
2	0.320	-1	0.32
3	0.344	-2	0.32
4	0.368	-3	0.32
5	0.392	-4	0.32
6	0.416	-5	0.32
7	0.440	-6	0.32
8	0.464	-7	0.32
9	0.488	-8	0.32
10	0.512	-9	0.32
11	0.536	-10	0.32
12	0.560	-11	0.32
13	0.560	-12	0.32
14	0.560	-13	0.32
15	0.560	-14	0.32
16	0.560	-15	0.32
17	0.560	-16	0.32
1	0.320	-17	0.32
0	0.320		

Table A.8 Unit fuel price description (Karpuz *et al*., 2008).

Fuel Type	Unit Fuel Price (TL/lt)
Diesel Fuel	2.55

Table A.9 Unit electricity cost description (Karpuz *et al*., 2008).

Definition	Unit Price (TL/kW)
Electricity	0.15

Table A.10 Employer descriptions (Karpuz *et al*., 2008).

Employee Description	Salary (TL)
Repairman	660
Labors in the Packing Plant	660
Dozer Operator	1,128
Formen	720
Administrative Personnel Type I	2,000
Administrative Personnel Type 2	1,500
Truck Driver	1,116
Engineer	2,000
Captain	3,000
Shift Captain	2,000
Oilman	660
Loader Operator	1,128