Management of Dry Flue Gas Desulfurization By-Products in Underground Mines

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PREFACE

This software program for evaluating economics of transportation systems for coal combustion by-products was developed by Dr. Hasan Sevim, Professor in the Department of Mining and Mineral Resources Engineering at Southern Illinois University at Carbondale and a co-investigator on this cooperative agreement. He was assisted in this effort by his students. This software has been demonstrated at several technical meetings. It has also been used by two graduate students to fulfill the requirements of their thesis towards their M. S. degrees.

We believe the software should have widespread applications in the coal and electric utility industries throughout the world.

**Yoginder P. Chugh
Program Director
May 5, 1998**

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1.0 INTRODUCTION

The DESEVAL-TRANS program is developed for the purpose of helping the engineer to design and economically evaluate coal combustion byproduct transportation systems that will operate between the power plant and the disposal site. This software was developed as a part of a cooperative research project entitled "Management of Dry Flue Gas Desulfurization By-Products in Underground Mines." The objective of the research project was to explore the technical, environmental and economic feasibility of disposing coal combustion byproducts in underground mines in Illinois. The research project was a cooperative program between the U.S. Department of Energy (USDOE) and the Department of Mining Engineering of Southern Illinois University at Carbondale (SIUC). The investigation had been conducted in six integrated topics: 1) Byproducts and Mix Characterization, 2) Materials Handling and Systems Economics, 3) Health and Safety Issues and Permitting, 4) Environmental Monitoring and Assessment, 5) Underground Placement, and 6) Field Demonstration. The DESEVAL-TRANS (short for Design and Evaluation of Transportation Systems) was developed in the Materials Handling and Systems Economics branch of the overall project. The detailed information on Materials Handling and Systems Economics was reported in a topical report (Sevim, 1996). The findings of the overall project, including materials handling and system economics, were submitted to USDOE in a final report (Chugh et al, 1998).

Four types of coal combustion byproducts were targeted for transportation and handling:

1. Conventional fly ash
2. Scrubber sludge
3. Fluidized Bed Combustion (FBC) fly ash
4. Spent-bed ash

Several transportation and handling systems that could handle these byproducts were examined. These technologies were classified under three general categories:

1. Truck
2. Rail
3. Container

As shown in Figure 1, an engineering design model was developed for each category. These models were keyed in Microsoft EXCEL spreadsheets and they are accessed independently. The purpose of design models is to determine the proper number of transport units, silo capacity, loading and unloading rates, underground placement capacity, number of shifts, etc., for a given case, defined by a distance-tonnage combination. The cost computation models were developed for the determination of the operating and capital costs. An economic evaluation model, which is common to all categories, was also developed to establish the cost-per-ton of byproduct transported. The cost and the economic evaluation models are accessed through Windows specifically developed for these models.

Various transportation systems can be configured under each major category depending on the type of byproduct transported. For instance, under the category of Truck, a dry byproduct can be transported in pneumatic trucks and a wet product in rear-dump trucks. Similarly, under the category of Rail, pressure differential rail cars can transport dry byproducts while coal hopper cars can transport both dry and wet byproducts. Containers on the other hand, can only handle dry byproducts.

Figure 1. DESEVAL-TRANS software structure for the design and economic evaluations of the systems under the three major categories of Trucks, Rail Cars, and Containers

The byproduct handling and transportation systems were analyzed in four modules as seen in Figure 2. The first two modules constitute the Primary Materials Handling Systems where the storage, handling and loading of the CCBs at the plant site, and their transportation from the plant to the mine site are addressed. The next two modules constitute the Secondary Materials Handling Systems where the unloading, storage and handling of the CCBs at the mine site and their transportation to the underground placement site are addressed. The integrated software developed in this project follows exactly these modules. The economic aspects of the 5th module, Underground Placement Operation, was also incorporated into this software

The use of DESEVAL-TRANS requires basic knowledge of EXCEL spreadsheets and WINDOWS operation.

Figure 2. Modules in transportation and handling of coal combustion by-products

2.0 HOW TO START THE SOFTWARE

To execute the programs in DESEVAL-TRANS, the PC must be equipped with WINDOWS-95. In the disk provided with this manual, there are three EXCEL files and several files related to WINDOWS application of DESEVAL-TRANS. It is suggested that the user creates a directory in "C" drive and stores all the files in this disk under that directory. The EXCEL files are for engineering design, and they are called RAIL.XLS, TRUCK.XLS, and CONTAINER.XLS. To have access to these files, activate EXCEL program and retrieve the desired file to start the engineering design.

The best way to use the WINDOWS application of DESEVAL-TRANS is to create an icon on the screen. To create this icon, go to WINDOWS EXPLORER program, reduce the size of the WINDOW, click on the ERTHA.EXE file, hold the clicked button down, drag the file outside of the WINDOW where you want the icon to appear and then release the button. You will see an icon composed of a truck, a rail car, and a container, all behind a big question mark, indicating that these transportation systems can be evaluated with the software. Once the icon is installed, the user can click the icon to call on the first window of the software where the menus are supplied. The use of the software will be explained in later sections of this manual.

3.0 A REVIEW OF TRANSPORTATION AND HANDLING SYSTEMS

Several T&H technologies were first evaluated from environmental point of view. These technologies can be classified under two categories:

1. Existing Technologies

1. 1. Pneumatic Trucks
1. 2. Pressure Differential Rail Cars
1. 3. Coal Hopper Cars
1. 4. Tarped Rear-Dump Trucks
1. 5. Bottom-Dump Container Trucks

2. Adaptable and Futuristic Technologies

2. 1. Collapsible Intermodal Containers
2. 2. Cylindrical Intermodal Tanks
2. 3. Coal Hopper Cars with Automatic Retractable Tarping
2. 4. Intermodal Steel Containers
2. 5. Covered Hopper Cars (Grain Cars)

Among the targeted byproducts in this research project, conventional fly ash can be either dry or wet depending on the storage method used at the power plant. Scrubber sludge, on the other hand is a wet product. FBC fly ash and spent-bed ash are dry products. Wet products would not contain more than 15 to 20 % moisture before it is transported to

mine site for underground placement purpose. If the product is wet and the distance between the plant and the mine is suitable, it can be transported in rear dump trucks. If the distance is long, it can be transported in coal hopper cars or containers loaded on the flatbed rail cars (except collapsible intermodal containers). Dry products can be transported in any of the above listed existing and futuristic T&H systems.

The first two technologies listed above under "Existing Technologies" are utilized in a number of operations throughout the United States in transporting dry byproducts. The third technology, Coal Hopper Cars, has found some application in CCB transportation, but the opinions have been mixed. When dry byproduct is transported in these cars, chemical sprays have been suggested, and applied, to the top surface to form a crusted layer to prevent fugitive dust while traveling. The major drawback in this alternative, even if the formation of a crust is successful, is the need of baghouses both at the loading and offloading points to prevent serious fugitive dust problem. Also, penetration of water or moisture through the crust, leading to heating or setting of the byproduct, may cause severe problems. There have been a few cases where the crust had to be broken with jackhammers.

The fourth technology, Tarped Rear-Dump Trucks, has also found application in CCB transportation. The major concern with tarped trucks is again the fugitive dust during loading and offloading of the material. A technology that is an improvement over to Tarped Rear-Dump Trucks is the Bottom-Dump Container Trucks. These trucks are used to fronthaul coal from mine to power plant and backhaul ash from plant to mine. At the mine site, the truck is driven on an artificially created gentle slope and its content is dumped from the bottom while traveling at a very slow pace. This technique minimizes the fugitive dust problem. A bulldozer later spreads the material and compacts it in order to maintain the shape of the slope. These trucks will not be very convenient in underground placement operations because the byproduct has to be offloaded directly from the tank into the injection hopper. With bottom dumping, there has to be a ramp arrangement for the truck to get to top of the hopper. These trucks, however, will be very convenient in surface disposal cases, especially when there is coal fronthauling.

Among the technologies cited in the second category above, the first, Collapsible Intermodal Containers, was developed by SEEC Inc. as a part of DOE-SIU cooperative agreement. This technology will be elaborated in the next section.

There have not been serious attempts to look into the technical and economic feasibility of the second and third technologies (Cylindrical Intermodal Tanks and Coal Hopper Cars with Automatic Retractable Tarping). These technologies were found to be environmentally friendly and very much adaptable to byproduct transportation, and therefore they are elaborated in the next section.

The fourth technology, Intermodal Steel Containers, was investigated as a part of the overall DOE-SIU cooperative agreement. These are 8x8x20 ft general-purpose containers. The modifications considered for adaptation to byproduct transportation were 1) a top gate to facilitate filling from ash silos, and 2) a rear-end valve or gate arrangement to offload the content into the injection system hopper.

Finally, the last technology, Grain Cars, was also found to be adaptable to byproduct transportation. The advantages of these cars are that they are abundantly available, and they can be loaded pneumatically or by gravity with minimal fugitive dust problem. However, they require an under-track bin at the mine site to dump the material. Rehandling of the residue from the under-track bin is not a desired feature. Offloading from these cars into pneumatic trucks is a possibility but retrofit for a fluidizing system may be costly. A solution to offloading problem, yet to be tested, could be the use of "portable direct rail-to-truck transfer unit" manufactured by Wilson Manufacturing and Design Inc., of Cecilia, Kentucky. Figure 3a depicts this unit in action between a pressure differential rail car and pneumatic truck. Figure 3b shows the dimensions of the unit. This is an articulated loader-conveyor system that can engage to rail car's gate with a large gasket and transfer the powdered byproduct through its enclosed chain (or screw) conveyor into a pneumatic truck. The capacity of the unit may range from 60 to 160 tph depending on the type of material conveyed. It has been reported that this unit has successfully transferred several types of powdered material (Wilson Manufacturing).

Figure 3 a Wilson's Articulating Conveyor Unit in Action between a Pressure Differential Rail Car and a Pneumatic Truck (Wilson Manufacturing and Design Inc.)

Figure 3 b Dimensions of a Wilson's Articulating Conveyor Unit (Wilson Manufacturing and Design, Inc.)

3.1 ENVIRONMENTALLY FRIENDLY TECHNOLOGIES

The first four technologies described below were found to be environmentally friendly and ready to be applied in the transportation and handling of the dry byproducts.

There is no significant environmental concern in the transportation and handling of the wet byproducts (15 to 20% moisture). They can be transported in rear-dump trucks, coal hopper cars, and intermodal containers other than collapsible containers.

3.1.1 Pneumatic Trucks (PT)

Pneumatic trucks, also referred to as bulk tank trucks, are widely used in transporting low density dry flowable powder and granular materials as well as high density materials such as cement, limestone and fly ash. A pneumatic truck is composed of three main components: (i) tractor, (ii) tank trailer, and (iii) blower. The most common method of loading the material is gravity feeding from a silo by a collapsible spout that engages to the gate on top of the tank. The tank is airtight when the lids of the gates are closed. During offloading, the material flows through the piping below the tank due to pressure difference created by the blower. Figures 4a and 4b show a pneumatic truck loading dry bulk material from a pressure differential rail car at Illinois Central Bulk Transfer Terminal at Harvey, Illinois.

The operating scenario that is conceived for PT system is schematically shown in Figure 5. The trucks are loaded from the fly ash bin of the plant and they deliver the material directly to the underground placement point at the mine site. There, the blower mounted on the truck supplies the pressure necessary for offloading the fly ash into the placement hopper. These trucks are approximately 20-25 tons in capacity and can offload the material in about 30-40 minutes.

It is noted that all truck systems will operate pretty much the same as the PT truck system.

Figure 4 a Side View of a Pneumatic Dry Bulk Transport Loading from a Pressure Differential Rail Car

Figure 4 b Back View of a Pneumatic Dry Bulk Transport Tank Loading from a Pressure Differential Rail Car

Figure 5 Dry FGD By-Product Transportation by Pneumatic Trucks

3.1.2 Pressure Differential Rail Cars (PD-car)

These are special types of rail cars used to handle powdered materials. They are operated under the principle of pressure differences between the car and the container to which the byproduct is discharged. As seen in Figures 4a and 4b, normally PD cars are complemented with pneumatic trucks at rail terminals to deliver the material to the final destination. When a PD car is pressurized to about 5 psi or more, the outlet valves are opened to form a steady flow of material into the truck until all the material in the compartment is cleared.

The operating scenario that is conceived for PD-car system is schematically shown in Figure 6. As seen, one set of cars is being filled at the power plant while the other set is being emptied at the mine. When all the cars at the plant are filled, either a "local train" or a "unit coal train" will take them to the mine. Similarly, the empty PD cars will be delivered to the plant for another round. At the mine, the byproduct in the PD cars will be transferred into a silo with the aid of a stationary blower. Delivery from the silo to the injection site can be done either by pneumatic trucks or by regular dump trucks if the silo is equipped with a pugmill to wet the byproduct to prevent fugitive dust.

This system has been in practice, with the exception of the underground injection, at a landfill operation in Blacksville, West Virginia, since 1994. Greenon Coal Co operates this site. The fly ash is loaded into 100-ton PD cars at a co-generation plant in New Jersey. In each trip, about 10 to 15 PD cars are attached to the unit train returning empty to West Virginia coal mines. At the Greenon facility, the PD cars are pushed to the emptying station, two at a time, by a track mobile (a tractor that can move both on rails and on road). At the station, the PD-car is hooked up to two sets of a pair of pressurized air lines; a 5 inch line to pressurize the car at about 13-15 psi, and an 8 inch line to provide the drag to transport the ash about 60 feet horizontally and 90 feet vertically to the top of a 240-ton silo. This silo is equipped with a baghouse to prevent fugitive dust. It takes about 45 minutes to empty a 100-ton PD-car. From the silo, fly ash is loaded into a 30-ton dump truck that delivers the load to the surface disposal area. To prevent fugitive dust, fly ash is treated with water in a pugmill before it is loaded into the truck (about 52 gallons of water is used for every ton of ash). At this operation, approximately 70,000 tons of fly ash was handled and disposed of during 1994.

Figure 6 Dry FGD By-Product Transportation by Pressure Differential Rail Cars

3.1.3 Collapsible Intermodal Containers (CICTM)

These containers are made of rubber coated aramid and nylon fabric with polyester webbing. SEECTM INC., which was one of the research partners in the DOE-SIUC cooperative agreement, patents them. The CICs are collapsible storage bins that are portable and intermodal - designed to ride inside coal cars, barges and trucks. Those CICs made to transport fly ash by riding in coal cars have a height of 120 inches, diameter of 110 inches and a 19-inch filling port. For ash of 60 lb/ft³ bulk density, the CIC capacity is about 20 tons. These containers are extremely durable and provide fully encapsulated transport, eliminating fugitive dust problems (Carpenter and Thomasson, 1995). Figure 7 shows a 20-ton CIC being lifted by an overhead crane.

The operating scenario that is conceived for CIC system is schematically shown in Figure 8. The coal train arrives at the plant and offloads coal into an under-track bin. Next, the CICs, which have already been filled with dry byproduct and staged along the rail, are lifted, one at a time, by an overhead crane and placed into the bays of the empty coal cars. Two specially designed lifting brackets mounted on both sides of the CIC facilitate lifting and placement by the crane into the bay of the car. Three or four CICs occupy a car, each taking one of the bays of a typical coal car. The overhead crane is on rubber tires and travels along the rail track looking inside the cars. When all the CICs are loaded, the train leaves for the mine.

At the mine site, an overhead crane lifts the CICs, one at a time, and places them on the concrete pad along the rail track. When all the CICs are offloaded, the train pulls under the silo for coal loading. After filling all the hopper cars, the train leaves for the power plant. The CICs are then loaded on tote trailer(s) by the same crane and transported to the underground placement site. There, the ash is offloaded into the hopper of placement system by the use of a vacuum system designed specifically for the CICs. The empty CIC can be transported back to the rail site on the same trailer. At the rail site, the empty bag is lifted with a small forklift, carried into a baghouse where the air trapped in the CIC is extracted. The collapsed bag is then retrieved by the forklift and hung like a vest onto the rail guides of a covered trailer. After collecting 25-40 empty CICs, the trailer is transported back to the plant.

At the plant, the tractor leaves the filled trailer, takes the empty trailer and drives back to the mine. The empty CICs are retrieved from the trailer with the help of a small forklift and placed, one at a time, on a specially designed trailer and pulled under the fly ash silo by a tractor. There, it is filled by gravity similar to filling a pneumatic truck. Then, the CIC is transported back to the rail site, where the trailer pulls under the overhead crane, and it is lifted and staged along the track and kept there until the coal train comes back from the mine.

Figure 7 A 20-ton CICTM Filled with Fly Ash, is being lifted by an Overhead Crane (SEECTM, Inc.)

Figure 8 Dry FGD By-Product Transportation by Collapsible Intermodal Containers

3.1.4 Cylindrical Intermodal Tanks (CIT)

These tanks are made of either steel or aluminum and have a volume of approximately 6400 gallons. They are used in transporting liquids. The capacity of a tank will be approximately 20 to 25 tons assuming an average density of 60 lbs/ft³ for coal combustion byproducts. Since they are cylindrical, the bridging and sticking problems that could occur in rectangular containers when handling powdered material like fly ash, or damp material like scrubber sludge, can be eliminated. These tanks may be mounted in steel frames to facilitate handling as shown in Figure 9. They can then be easily handled with a piggy packer (a specialized crane) as shown in Figure 10.

The operating scenario that is conceived for CIT system is schematically shown in Figure 11. At the plant, an empty tank will be placed on a trailer with the aid of a piggy packer and shuttled to byproduct storage silo where it will be filled like a pneumatic truck. At the rail siding, the piggy packer will lift the filled tank and stage it along the railroad on a concrete pad. When the train arrives, the piggy packer will lift these tanks again one by one and place them on flatbed rail cars. The lengths of these rail cars are suitable to handle 3 of these tanks on one car.

At the mine site, the tanks will be lifted again by a piggy packer and placed on the concrete pad. After the unloading is completed, the same packer will lift the tanks one by one and place them on a trailer to be taken to the injection site. The unloading of the residue into the injection hopper will be done by elevating the head of the tank with the aid of a hydraulic jack mounted on the trailer. The gate of the tank will then be opened and the content transferred into the injection system hopper. If emptying the tank through a flop gate creates unacceptable levels of fugitive dust, they can be designed to be emptied like a pneumatic truck with the aid of a portable blower attached to the injection hopper.

The empty tanks will be staged at the rail siding and will be waiting for the train to pick them up. After delivering the empty tanks to the plant another cycle will begin.

Figure 9 A 20 ton Cylindrical Aluminum Tank Mounted on a Steel Frame and Placed on a Trailer Chassis

Figure 10 Piggy Packer Placing a Container on a Trailer

Figure 11 Dry FGD By-Product Transportation by Cylindrical Intermodal Tanks

4.0 THE INTEGRATED SOFTWARE

The analysis of several T&H systems revealed that there were too many variables to be considered in the selection of a T&H system. It is decided that software be developed to facilitate the design and economic evaluation of prospective systems. The investigation led to the conclusion that the T&H systems can be identified under 3 major categories: Truck, Rail, and Container. The developed software is general enough that any system configuration that can be identified with one of these generic categories can be evaluated using this software. As seen in Figure 12, the evaluation of any of the selected T&H technologies is done in three steps:

1. Engineering design computations,
2. Capital and operating cost computations,
3. Economic evaluation

Figure 12. DESEVAL-TRANS software structure for the design and economic evaluations of the systems under the three major categories of Trucks, Rail Cars, and Containers

The engineering design computations are performed on spreadsheets. These spreadsheets are accessed independently and the results are fed in the cost computation software. The economic evaluation software is common to all technologies. A Windows application was developed for the second and third steps covering the cost computations and economic evaluation. The different components of the software and their uses will be presented below.

4.1 Engineering design computations

To perform the engineering design computations, a spreadsheet was developed using Microsoft EXCEL software for each major category. In these spreadsheets, operating schedules composed of plant schedule, transportation schedule between the plant and the mine, and mine schedule, are devised; and critical system parameters such as silo capacities, number of transportation units, loading rate, transloading rate, and injection rate are calculated for a given tonnage-distance combination.

4.1.1 Engineering design for Truck systems

The spreadsheet developed for CCB transportation using trucks is shown in Table 1. It is noted that this spreadsheet can actually be used for any type of truck transportation - tarped or open rear-dump trucks, bottom-dump container trucks, trailer mounted containers, etc. In Table 1, the first two blocks of data are user defined. The first block - line 1 to 3 - defines the operating schedule, whereas the second block - line 5 to 11 - defines values of operation parameters. The third block printed in bold letters, exhibits the values of the design parameters calculated using the input data from the first two blocks. The two most important variables that affect the design of a system are the transportation distance and tonnage transported. For illustration purposes, three cases, formed by three distance-tonnage combinations, were given in this table.

For example, for a tonnage-distance combination of 100,000 tons and 100 miles (second column), the cycle time of a truck is found to be 133.3 minutes by adding loading time (line 5), travel time loaded (line 13), unloading time (line 8), and travel time empty (line 14). Another important parameter is the "maximum number of trucks without queuing". This is the maximum number of trucks in a fleet that would operate without waiting in line at either end of the operation. It is obtained by dividing the cycle time to the greater of the unloading time or loading time (133.3/20 in this example). The "required number of trucks" (line 20) to deliver the targeted tonnage, on the other hand, is calculated by dividing the "required number of trips per day" (line 18) to "maximum number of trips per truck per shift" (row 19). If the "required number of trucks" is smaller than the "maximum number of trucks without queuing," the scenario receives a "yes" (line 23) for its feasibility. Otherwise, the unloading time is decreased (line 8), or equivalently, the injection rate is increased (line 21) and the new scenario is re-tested for feasibility. It is noted that the upper limit for increased injection rate is assumed to be 2 tons/minute.

Any scenario that requires more than 2 tons/minute to become feasible should be rejected.

The plant silo capacity is shown in lines 24 and 25. Assuming two idle shifts on Saturday and no work on Sunday, total fly ash accumulation hours at the plant adds up to 40 hours. This translates into an accumulation of 457 tons when the annual production is 100,000 tons. If the plant does not have a silo to accommodate this accumulation, either the operating schedule has to be changed or extra storage capacity has to be built in the system.

An important point in the determination of the truck fleet size should be mentioned here. The "required number of trucks" calculated in the engineering design spreadsheet will in most cases fall short of transporting the annual production due to the fact that the availability of a truck will always be less than 100 %. For instance, in the 100,000 tons - 100 miles combination, the required number of trucks was calculated to be 10.21 as seen in Table 1. This number was rounded to 10 and entered in the cost computation spreadsheet where it was subjected to "availability" concept. It is assumed that each truck in the fleet will have 90 % availability.

With ten trucks, the availability of the fleet will be 0.9^{10} , or simply 0.348 (approximately 35 %). This is an unacceptable level of availability. Therefore, it is resolved in this design that the fleet availability must be at least 85 %. The number of trucks that would provide such availability is then calculated by the use of the Binomial probability distribution. This number was found to be 12 for the above combination. The Binomial probability distribution and the computation of the number of trucks for the above case are given in the Appendix.

Table 1. Engineering design computations in CCB transportation by trucks

1	Annual Production (tons)	100000	100000	100000
2	Distance (miles)	30	100	200
3	Shifts per day	1	1	1
4				
5	Loading time (min)	10	10	10
6	Average speed loaded (mph)	45	45	45
7	Average speed empty (mph)	45	45	45
8	Unloading time (min)	29	29	29
9	Duration of a shift (min)	480	480	480
10	Work days per year	312	312	312
11	Truck payload (tons)	20	20	20
12				
13	Travel time loaded (min)	40.0	133.3	266.7
14	Travel time empty (min)	40.0	133.3	266.7
15	Cycle time (min)	119.0	305.7	572.3
16	Maximum number of trucks without queuing	4.10	10.54	19.74
17	Required number of trips per year	5000	5000	5000
18	Required number of trips per day	16.03	16.03	16.03
19	Maximum number of trips per truck per shift	4.03	1.57	0.84
20	Required number of trucks	3.97	10.21	19.11
21	Injection rate (tpm)	0.69	0.69	0.69
22	Injection system capacity (tph)	41	41	41
23	Feasible scenario?	Yes	Yes	Yes
24	Max. ash accumulation time (hrs)	40	40	40
25	Max. ash accumulation (tons)	457	457	457

How to use this spreadsheet:

1. Go to EXCEL
2. Open file "TRUCK" under the directory it is saved (the directory will be the user-created directory).

4.1.2 Engineering design for Rail systems

The spreadsheet developed for CCB transportation using rail cars is shown in Table 2. This spreadsheet can be used for both the pressure differential rail cars, presented in Section 2.1.2, and the coal hopper cars. As seen in Table 2, the spreadsheet is divided in two sections; plant site and disposal site. The first block in plant site (lines 1 to 7)

corresponds to user defined data, whereas the second block (lines 9 to 17), marked in bold letters, corresponds to calculated values of the design parameters for the operations at the utility plant site. An important value in the user-defined block is "the number of trips per week" (line 4) which is a determining factor of the number rail cars needed in the system (line 11). Obviously, the more the trips per week the less the number of rail cars, and consequently, the less the capital investment. However, the number of trips that can be scheduled depends on the location of the plant and the mine, as well as the flexibility of the Rail Company operating within the area.

Another important value is the silo capacity at the plant (line 16). As seen on line 15, for 100 miles transportation distance, the train cycle time is estimated to be 28.4 hours. During this time period, the CCB produced in the plant has to be stored. At a continuous-flow rate of 0.191 tpm (line 9), a silo of 326 tons (line 16) is needed. Since the user reports an existing silo of only 100 tons (line 5), a warning is given on line 17 to "increase" the silo capacity. If for any reason this extra capacity can not be provided, then the operating schedule must be changed.

The first block of the second section is again for the user-defined data, whereas the second block is for the calculated values of the design parameters pertaining to disposal site. In the user-input block, a suggestion was provided for "shifts per day" (Line 22). In this suggestion it is assumed that the maximum injection rate will be 100 tph and that the injection system functions 6 hours/shift, 6 days/week, and 52 weeks/year, totaling to 187,200 tons per year. If this assumption does not hold, the user should enter his/her choice. In the calculated-values block, Here, the calculated transloading rate from the rail-car into the silo (line 32) is based on 480 minutes of continuous operation (line 23) in a shift. Similarly, the injection rate of 0.89 tpm (line 34) is based on 360 minutes of continuous operation (line 24). If these times are not realistic, they should be changed. Finally, in the last line of this block it is seen that three trucks will be sufficient to transport 100,000 tons annually from the silo to the injection point. In another operating scenario, however, silo may be totally omitted at the mine site, and trucks can be used between the PD cars and the injection system. In such a scenario, rails cars will play the role of a silo, and the variable "transloading rate from train to silo" (Line 32) becomes irrelevant. Then, the user has to enter the appropriate value for the variable "truck loading time from rail car" (Line 28) for proper determination of the number of trucks in the fleet (Line 37).

How to use this spreadsheet:

3. Go to EXCEL
4. Open file "RAIL" under the directory it is saved (the directory will be the user-created directory).

Table 2. Engineering design computations in CCB transportation by rail cars

	PLANT SITE:			
1	Distance between the plant and the mine (miles)	30	100	200
2	Annual residue production (tons)	100000	100000	100000
3	Railcar capacity (tons)	100	100	100
4	Number of trips per week	1	1	1
5	Existing silo capacity (tons)	100	100	100
6	Average speed of train (mph)	45	45	45
7	Time between delivery of filled cars and pick-up of the empties (hours)	24	24	24
8				
9	Continuous flow rate from plant into silo (tpm)	0.191	0.191	0.191
10	Weekly residue production (tons)	1923	1923	1923
11	Required number of PD cars per trip	19.23	19.23	19.23
12	Final number of PD cars per trip	19	19	19
13	Tonnage transported per trip (tons)	1923	1923	1923
14	Round trip time (hours)	1.333	4.444	8.889
15	Total time for train arrival at plant (hours)	25.333	28.444	32.889
16	Minimum required silo capacity at plant (tons)	290	326	376
17	Need to adjust the silo capacity?	increase	increase	increase
18				
19	DISPOSAL SITE:			
20	Number of working weeks per year	52	52	52
21	Working days per week	6	6	6
22	Shifts per day (100 tph inj. rate is max, so $100 \times 6 \times 6 \times 52 = 187200t$)	1	1	1
23	Transloading time per shift (minutes)	480	480	480
24	Injection time per shift (minutes)	360	360	360
25	Truck capacity (tons)	20	20	20
26	Truck travel time empty (minutes)	10	10	10
27	Truck travel time loaded (minutes)	10	10	10
28	Truck loading time from silo (or from rail car, minutes)	10	10	10
29	Truck unloading time into injection hopper (minutes)	20	20	20
30				
31	Truck cycle time (minutes)	50	50	50
32	Transloading rate from train to silo (tpm)	0.668	0.668	0.668
33	Silo capacity (one shift injection, tons)	321	321	321
34	Injection rate (tpm)	0.890	0.890	0.890
35	Injection capacity (tph)	54	54	54
36	Number of trucks in the fleet	2.226	2.226	2.226
37	Final number of trucks in the fleet	3	3	3

4.1.3 Engineering design for Container systems

The spreadsheet developed for CCB transportation using Container systems is shown in Table 3. Two container systems were introduced in Sections 2.1.3 and 2.1.4. Both systems, as well as any other container system, can be evaluated using this spreadsheet. The content of Table 3 is very much similar to that of the "Rail" presented in Section 3.1.2, except that there is an extra operation of container transfer and container loading at

the plant site, which requires the determination of the right number of tote trailers (Line 25). If, however, the facility provides direct loading of the containers from the silo while they are on the flatbed rail car, this extra operation can be avoided.

Table 3. Engineering design computations in CCB transportation by containers

	PLANT SITE:			
1	Distance between the plant and the mine (miles)	30	100	200
2	Annual by-product production (tons)	100000	100000	100000
3	Container capacity (tons)	20	20	20
4	Number of trips per week	1	1	1
5	Existing silo capacity (tons)	100	100	100
6	Average speed of train (mph)	45	45	45
7	Time between delivery of filled cars and pick-up of the empties (hours)	24	24	24
8	Number of work weeks per year	52	52	52
9	Number of work days per week	7	7	7
10	Number of shifts per day	1	1	1
11	Duration of a shift (minutes)	480	480	480
12	Cycle time for filling one container (minutes)	30	30	30
13				
14	Continuous flow rate from plant into silo (tpm)	0.191	0.191	0.191
15	Weekly residue production (tons)	1923	1923	1923
16	Required number of containers per trip	96.15	96.15	96.15
17	Final number of containers per trip	96	96	96
18	Tonnage transported per trip (tons)	1923	1923	1923
19	Round trip time (hours)	1.333	4.444	8.889
20	Total time for train arrival at plant (hours)	25.333	28.444	32.889
21	Minimum required silo capacity at plant (tons)	290	326	376
22	Need to adjust the silo capacity?	increase	increase	increase
23	Storage and staging area (twice the area of containers - sq. ft)	38400	38400	38400
24	Total number of containers filled per shift per trailer	16	16	16
25	Number of tote trailers	1	1	1
26				
27	DISPOSAL SITE:			
28	Number of work weeks per year	52	52	52
29	Work days per week	6	6	6
30	Injection time per shift (minutes)	360	360	360
31	Shifts per day (100 tph inj. rate is max, so $100 \times 6 \times 6 \times 52 = 187200t$)	1	1	1
32	Tote trailer travel time empty (minutes)	10	10	10
33	Tote trailer travel time loaded (minutes)	10	10	10
34	Time to load a container on trailer (minutes)	5	5	5
35	Time to unload byproduct from container into injection hopper (minutes)	5	5	5
36				
37	Tote trailer cycle time (minutes)	30	30	30
38	Total number of containers transported per shift per trailer	12	12	12
39	Number of tote trailers	2	2	2
40	Storage and staging area (twice the area of all containers - sq. ft)	76800	76800	76800
41	Injection rate (tpm)	0.890	0.890	0.890
42	Injection system capacity (tph)	53	53	53

How to use this spreadsheet:

5. Go to EXCEL
6. Open file "CONTAINER" under the directory it is saved (the directory will be the user-created directory).

4.2 Cost computations

To perform capital and operating cost calculations, a spreadsheet was developed using Microsoft EXCEL software for each major T&H category. These spreadsheets were assembled "under one roof" using "Delphi", a rapid application development (RAD) tool. Under this roof, sketches of the systems and an economic evaluation model were also added. The sketches were drawn using Microsoft Power Point, and economic evaluation model was coded using FORTRAN language. The final byproduct was a user friendly, interactive WINDOWS application.

In this WINDOWS application, the spreadsheets were converted into templates. The case presented in the templates corresponds to a 100-mile transportation distance and 100,000 tons of annual byproduct delivery. When the user selects one of the major categories from the menu, the input data are presented to him in various dialog boxes. Clicking on a particular data entry can retrieve the source of that entry. If the entry is not satisfactory, the user can overwrite it by typing in his or her preferred value. In other words, default values are provided for every entry in the template of the selected T&H system.

With the organization of data in dialog boxes, the user can conveniently input parameter values and see the results of cost calculations right on the spot without the need to know the underlying structure. Helpful plots of system schematics and item explanations are shown on the screen as item-sensitive features. For instance, as shown in Figure 13, by selecting the "Alternatives" menu item from the menu bar, the user calls the sub-menu that shows the three major T&H categories that were built in the software. When the user

Figure 13 First Window in the Evaluation of a Truck System

clicks on the "Rail" alternative, the software brings the sketch of the system to the screen. The description of the system operation appears on the box next to the sketch. To follow system description, simply place the cursor in the box and keep pressing down-arrow key. As seen in Figure 13, the menu bar shows titles for six menus for the evaluation of a system. The functions of these menus are briefly described below. For the evaluation of a system, these menus must be followed in the order they are given.

File:

Open:	Opens an existing file
Save:	Saves a file that has been edited
Save As:	Saves a new file
Print:	Prints the file that has been edited
About:	Provides information about the software
Exit:	Exits the software

Alternatives:

Truck:	Initiates Truck transportation template
Rail:	Initiates Rail transportation template
Container:	Initiates Container transportation template

Parameters:

Initiates the template for data that is called "General Parameters" for the specific case

Unit Costs:

Capital:	Values of capital cost items are entered
Operating:	Values of operating cost items are entered

Scheduling:

Power Plant:	Information on the operations at power plant site is entered
Mine Site:	Information on the operations at mine site is entered

Evaluation:

Cost Calculation:	Capital and operating costs computations for both power plant and mine sites are performed
Financial Data:	Data necessary for economic evaluation of the case is entered and processed
Start Evaluation:	When clicked, the economic evaluation of the case is conducted and the output is displayed on the screen

5.0 EVALUATION OF TRANSPORTATION AND HANDLING SYSTEMS

Evaluation of a system starts by selecting a category under the "Alternatives" menu. The user then begins examining the default template values under different dialog boxes. After making the necessary changes, each dialog box is saved by clicking on an "OK"

key located at the bottom of the dialog box. When the entries in "Scheduling" menu are completed, the file can be saved under an appropriate name by going back to the "File" menu and clicking "Save As" button. It is suggested that a user-created file be saved in a directory different than the directory where the files of DESEVAL-TRANS are saved. This will simplify file management when numerous files are created. In the following, a "Truck" system evaluation will be demonstrated from the beginning to the end.

5.1 Evaluation of a truck system

First step in using DESEVAL-TRANS is to click the Icon, which will bring the menus and software introduction statement to the screen. The evaluation will start by either retrieving an old file or by creating a new file using the template. The steps in the creation (or in the edition) of a file are given below.

1. Click the "Alternative" menu button to exhibit the three main categories: Rail, Truck, and Container.
2. Click the "Truck" button to bring the sketch of the system-operating scenario, along with a description of the system.
3. Click the "Parameters" button to bring the dialog box shown in Figure 13. The first column on this dialog box shows the description of the variables. The second column shows the reference number of the variables. For instance "P5" means, fifth variable in "Parameters" dialog box. The third column shows the default values of the variables. All templates were created for distance-tonnage combination of 100 miles and 100,000 tons. Therefore, all values shown in the dialog boxes will correspond to this case. The user must change these values if they are not satisfactory. To change a value, simply move the cursor to the cell where the value is shown, type in the correct value and hit the "enter" button on the keyboard. Failure of hitting the "enter" button will keep the old value in that cell. The forth column will exhibit either the letter "i" or "c" or "nc", which will indicate "input", "calculated", and "newly calculated", respectively. If a value is inputted from the keyboard, letter "i" will appear in that cell. If a value is calculated internally, letter "c" will appear in that cell. If a value is recalculated because of a change in one or more of its determinants, letter "nc" will appear in that cell.

It is noted that brief descriptions of the entries are stored in the software. Clicking in the cell, where the variable name appears, will bring the "Information" box for that variable. The source of the entry, or the assumptions made in its calculation, will be shown in this box.

4. Click the "OK" button to save the "Parameters" dialog box if all the values entered are correct. Click the "CANCEL" button if the changes made are not correct. This action will preserve the original values in the dialog.

The section of the EXCEL spreadsheet from which the "Parameters" dialog box was built is shown in Table 4. In the rest of this manual, only the sections of EXCEL spreadsheets will be shown in place of Windows dialog boxes.

Table 4. The EXCEL spreadsheet background of the "Parameters" dialog box

GENERAL PARAMETERS:	
Distance between power plant and mine (miles)	100
Annual amount of byproduct to be handled (tons)	100000
Project life (years)	5
Truck capacity (tons)	20
Availability of a truck (in decimal)	0.9
Number of front tires	10
Number of rear tires	8
Front tire replacement frequency (miles)	75000
Rear tire replacement frequency (miles)	150000
Average depth of the mine (feet)	300

5. Click the "Unit Costs" button, which will exhibit the "Capital" and "Operating" items.
6. Click the "Capital" button to bring the dialog box. The content of this dialog box is shown in Table 5. Make the necessary changes in the dialog box and send it back by clicking the "OK" button. If there is no change, the user can click either the "OK" button or the "CANCEL" button.

Table 5. The EXCEL spreadsheet background of the "Capital" dialog box

CAPITAL COST ITEMS:	
Cost of a tractor	70000
Cost of a tank trailer	45000
Cost of a blower	5000
Total cost of a truck (tractor-trailer-blower)	120000

7. Click the "Operating" button to bring the dialog box. The content of this dialog box is shown in Table 6. Examine the parameters in the dialog box, make necessary changes and send it back.

Table 6. The EXCEL spreadsheet background of the "Capital" dialog box

OPERATING COST ITEMS:	
Truck leasing cost (\$/year)	0
Fuel consumption (miles per gallon)	5
Fuel cost (\$/gallon)	1.1
Insurance cost per truck	7500
License cost per truck	2222
Annual highway tax per truck	550
Tire cost (each)	325
Maintenance cost (\$/mile)	0.14
Wage for truck drivers (\$/hr)	20
Wage for silo operator (\$/hr)	20
Overhead cost (% of other operating costs - in decimal)	0.1
Cost of road construction (\$/sq. yd)	5
Average cost of injection hole (\$/ft)	20

8. Click the "Scheduling" button to bring the "Power Plant" and "Mine Site" items.
9. Click the "Power Plant" button to bring the dialog box. The content of this dialog box is shown in Table 7. Examine the parameters in the dialog box, make necessary changes and send it back.

Table 7. The EXCEL spreadsheet background of the "Power Plant" dialog box

POWER PLANT:	
Do we need silo (1 for yes, 0 for no)?	0
Silo capacity (from engr. design sheet - tons)	434
Truck cycle time (from engr. design sheet - minutes)	275
Number of working days per year (from engr. design sheet)	312
Number of shifts per day (from engr. design sheet)	1
Duration of a shift (from engr. design sheet - hours)	10
Number of trips per day (from engr. design sheet)	16.03
Number of trucks required (from engr. design sheet)	7.35
Number of trucks required (rounded)	8
Number of trucks to have at least 80% fleet availability	10
Actual fleet availability	0.93
Number of drivers required	8
Number of silo operators per shift	1
Total number of silo operators	1

10. Click the "Mine Site" button to bring the dialog box. The content of this dialog box is shown in Table 8. Examine the parameters in the dialog box, make necessary changes and send it back.

Table 8. The EXCEL spreadsheet background of the "Mine Site" dialog box

MINE SITE:	
Do we have silo (1 for yes, 0 for no)	0
Silo capacity (tons)	0
Area of new road to be constructed (sq. yd/year)	14000
Expected amount of byproduct injected through one hole (tons)	10000
Number of injection holes to be drilled per year	10
Injection system capacity (from engr. design sheet - tph)	48
Do we have hydraulic injection system (1 for yes, 0 for no)?	1
Do we have pneumatic injection system (1 for yes, 0 for no)?	0
Operating cost of hydraulic injection system (\$/ton)	3.400
Operating cost of pneumatic injection system (\$/ton)	0.000
Injection system operating cost (\$/ton)	3.400

11. Click the "Evaluation" button to bring the "Cost Calculation", "Financial Data", and "Start Evaluation" items.
12. Click the "Cost Calculation" button to bring the dialog box. The content of this dialog box is shown in Table 9. As seen, this section of the software performs the cost computations using the information supplied in preceding dialog boxes. The end result is "TOTAL SYSTEM CAPITAL COST", "TOTAL SYSTEM OPERATING COST" and "Operating cost per ton". The "TOTAL SYSTEM CAPITAL COST" is the initial capital investment for the project, whereas the "TOTAL SYSTEM OPERATING COST" is the annual cost of the operation. The "Operating cost per ton" is obtained by dividing the "TOTAL SYSTEM OPERATING COST" to annual amount of byproduct delivered (or disposed of).

Table 9. The EXCEL spreadsheet background of the "Cost Calculation" dialog box

PLANT CAPITAL COSTS:	
Trucks	1200000
Silo	0
Other (1)	0
Other (2)	0
Other (3)	0
Total plant capital cost	1200000
PLANT OPERATING COSTS:	
Leasing cost for trucks	0
Fuel	220059
Insurance	75000
License for tractor-trailer	22220

Highway tax	5500
Front tire replacement	43345
Rear tire replacement	17338
Maintenance	140038
Driver wages	499200
Silo operators wages	62400
Other (1)	0
Other (2)	0
Other (3)	0
Subtotal	1085100
Overhead cost	108510
Total plant operating cost	1193610
MINE CAPITAL COSTS:	
Hydraulic injection system	242259
Pneumatic injection system	0
Silo	0
Other (1)	0
Other (2)	0
Other (3)	0
Total mine capital cost	242259
MINE OPERATING COSTS:	
Road construction cost	70000
Injection system operating cost	339955
Cost of injection holes	60000
Other (1)	0
Other (2)	0
Other (3)	0
Subtotal	469955
Overhead cost	46996
Total mine operating cost	516951
TOTAL SYSTEM CAPITAL COST	1442259
TOTAL SYSTEM OPERATING COST	1710560.94
Operating cost per ton	17.11

It is noted that the user can change the calculated values in this dialog box by simply moving the cursor to the cell where the change is desired, typing in the new value, and hitting the return key. The values that are dependent on the modified value will automatically change.

As seen in this dialog box, the injection system operating and capital costs were also included in the computations. The user can calculate the transportation cost alone by either setting the values of the variables pertaining to injection system in preceding dialog boxes to "0", or by simply setting them to "0" in this box. Also, three

additional rows called "Other ()" are provided under the sections of "PLANT CAPITAL COSTS" "PLANT OPERATING COSTS", "MINE CAPITAL COSTS", and "MINE OPERATING COSTS". These rows can be used for any cost items that are not thought of in the initial construction of the model, and that the user wants to include them in his/her case. For instance, in the evaluation of underground placement system, the land may not belong to the Coal Company, in which case land leasing and land reclamation costs must be part of the overall cost. The "Other ()" items under "MINE OPERATING COSTS" could then be used to enter these costs. Similarly, equipment such as a front-end-loader or a truck that would be used in the underground placement operation could be reported in "OTHER ()" line under "MINE CAPITAL COSTS" section.

There is no "OK" or "Cancel" button on this dialog box. If the calculated values are acceptable, one can simply move on to the next step of evaluation.

13. Click on the "Evaluation" button again to bring the menu. Then, click on the "Financial Data" button to bring the dialog box. This dialog box is shown in Figure 14. As seen, the first part of the box pertains to capital cost items, and their depreciation and economic lives. The values in the cells are entered by moving the cursor on the targeted cell and then typing the value in "Change To" cell. For correctly filling these values, the user should refer to PLANT CAPITAL COST and MINE CAPITAL COST sections of "Cost Calculation" dialog box.

The second column, titled "Investment Year", indicates the year the capital cost item is acquired. The third column, "Depreciation Life", reflects the appropriate depreciation life categories from "Modified Accelerated Cost Recovery System (MACRS)". Details of this depreciation method can be found in Publication 534 of US Department of Interior, Internal Revenue Service. The forth column, "Starting Year", shows the year in which the capital cost item will start depreciating. The economic lives, shown in the last column, are used in the computation of salvage values.

The second part of the dialog box exhibits the discount rate, tax rate, salvage value, and price. The discount rate is the "minimum required rate of return" that the company handling the project would want to make on its investment. The tax rate is an effective tax rate reflecting both the state and the federal taxes. The method of evaluation that is incorporated into this software is an after-tax method, which requires a discount rate and a tax rate. This method will be briefly described in the next session.

The salvage value is the remaining value of a capital cost item at the end of the project life. This value is calculated by using the straight-line depreciation method. For instance, if in a 5-year project, a capital cost item costs \$100,000 and has an economic life of 10 years, the salvage value of the item at the end of 5 years will be \$50,000 $((100,000 - (100,000/10)*5))$. The value shown in the dialog box reflects the market value of all the capital cost items in the project.

Figure 14 Window for Financial Data in the Evaluation of a Truck System

The "price" is the cost a contractor would charge the power plant to transport and dispose the byproduct. If either the power plant or the mining company undertakes the project, there would be no need for "price" since one would be interested in finding only the "cost-per-ton" of product transported and disposed of. It is expected that the contractor would ask a price that would generate necessary revenues to earn the minimum required rate of return on the investment. Whether this is happening or not will be checked from the "AFTER-TAX NET PRESENT VALUE" line of economic evaluation output table (shown in the next section). A positive value on this line will indicate a rate return greater than the expected rate whereas a negative value will indicate the opposite. A value that is exactly equal to "0" means that the project is exactly making the minimum required rate of return.

When the entries are completed, clicking on the "OK" button saves the dialog box. This is the point to save all the dialog boxes under a desired file name for future use and reference. As an example, let us assume that the file is saved under the name "ASH". With this, two more files will be automatically created and saved; the first one will be called ASH.FN, which will store the data entered in "Financial Dialog Box", and the second one will be called ASH.OUT, which will store the economic evaluation output table. If the file is not saved under a specific name, only the last two files will be saved under the name ERTHA*.IN and ERTHA*.OUT. The "*" sign will take the values of 1, 2, and 3 for Rail, Truck, and Container system evaluations, respectively. These files will be overwritten every time a run is made and the input file is not saved.

14. Click on the "Evaluation" button to bring the menu back. Then, click on the "Evaluation" button, which will activate the economic evaluation model. The output table will immediately appear on the screen. To print out this table, click on the "File" button first and then on the "Print" button. A sample output table is shown in the next section.

5.2 Economic Evaluation

The economic evaluation model receives its input from dialog boxes under the menus: General, Cost Calculation, and Financial Data. The algorithm developed for this purpose is based on the principle of the "Net Cash Cost" (NCC) method, also known as "After-Tax Cost" method. The After-Tax method is preferred to Before-Tax method because, as stated by Stermole and Stermole (1990), "The effects of tax considerations often vary widely from one investment alternative to another, so it generally is imperative to compare the relative economies of investment alternatives on an after-tax basis to have a valid economic analysis."

Table 10 exhibits a typical output of "Economic Evaluation" software. The case shown in the table is the same case given in the preceding section where a Truck system transports 100,000 tons annually to a mine 100 miles away from the plant. It is assumed that the project life is 5 years, the effective tax rate is 40%, and the minimum required rate of return is 12%.

In each year of the project life, the NCC is calculated using Equation 1.

$$\text{NCC} = (\text{Operating Cost} + \text{Depreciation}) (1 - \text{Tax Rate}) - \text{Depreciation} + \text{Capital Cost} \dots \text{Eq. (1)}$$

The depreciation allowances are calculated based on the "Modified Accelerated Cost Recovery System" MACRS. Also in this model, the "constant dollar" approach is preferred to the "escalated dollar" because it allows the use of "today's dollars" for cost estimations assuming that the cost escalation is equal to the inflation rate throughout the project life. This approach eliminates the complexity of estimating the future cost escalation (Stermole and Stermole, 1990).

As seen in Table 10, the net cash flows of years 1 to 5 are negative since only costs are involved in the analysis, and the objective is to find the price to be charged per ton of material delivered in order to make the minimum required rate of return. The net cash flow of year "0" simply reflects the initial capital cost invested in the project, which is \$1,442,000 in this case. The NCCs calculated for each year are discounted to time "0" at the "minimum required rate of return" to obtain the Net Present Cost (NPC) of the project. The NPC is subsequently annualized over the project life using the same discount rate. The annualized cost is then divided by the annual tonnage of byproduct transported and placed underground to obtain the cost-per-ton value. Since this is an after-tax value, the "price to be charged" is obtained by dividing this value by (1 - tax rate).

In the example given above, the salvage value after 5 years of operation is estimated to be \$640,000. Two capital-cost items, trucks and hydraulic injection system, are depreciated within 5 and 3 years, respectively. Hence, at the end of 5-year project life, only 5.76% of the trucks had not yet been depreciated. This amounted to approximately \$69,000 as the book value at the end of fifth year. The difference between the salvage value and the book value constitutes the capital gain of the project that is subjected to 40%, leading to an after-tax cash flow of \$412,000. Again, as seen in Table 10, at 12% minimum required rate of return, the annual equivalent cost of the project is determined to be \$1,244,000 indicating an after-tax cost per ton of \$12.44. It is noted that this cost includes the injection cost too. At 40% effective tax rate, the \$11.61 after-tax cost corresponds to a before-tax price of \$19.36. In other words, the company who undertakes this project must charge \$20.73 per ton to obtain a 12% rate of return on its investment. However, if the project is undertaken by either the company who owns the power plant or the mine, it will cost them \$12.44 per ton, and this cost will be absorbed within the company as part of their overall operating cost.

In the above example, it is assumed that the company, which handles the byproducts, chooses to purchase, and therefore capitalize, the system components such as trucks and injection system. If leasing of these components is a possibility, a leasing analysis can be conducted in addition to capitalization analysis so that a comparison can be made. The model has both options built in as can be seen from data entries in Tables 6 and 9.

Table 10. An example of economic evaluation of byproduct transportation using trucks
(including underground placement system)

BYPRODUCT TRANSPORTATION BY TRUCK SYSTEM

DISTANCE (MILES) ----- = 100
 PRODUCTION (TONS/YEAR) ----- = 100000
 MINIMUM REQUIRED RATE OF RETURN (%) ----- = 12
 EFFECTIVE TAX RATE (%) ----- = 40
 PRICE TO BE CHARGED (\$/TON) ----- = 0

Year	0	1	2	3	4	5
Revenue.....	0	0	0	0	0	0
-Oper. Cost.....	0	-1708	-1708	-1708	-1708	-1708
-Depreciation...	0	-321	-492	-266	-156	-138
Taxable Income..	0	-2029	-2200	-1974	-1864	-1846
-Tax.....	0	811	880	790	746	738
Net Income.....	0	-1217	-1320	-1185	-1119	-1108
+Depreciation...	0	321	492	266	156	138
-Capital Cost...	-1442	0	0	0	0	0
Net Cash Flow...	-1442	-897	-828	-918	-962	-970

CAPITAL GAIN (OR LOSS) COMPUTATION (\$1,000)

Salvage Value.....	640
Book Value.....	-69
Capital Gain (or Loss).....	571
Tax Liability.....	-229
After-Tax Capital Gain (or Loss).....	343
Book Value.....	69
After-Tax Cash Flow Due to Cap. Gain (or Loss)...	412

AFTER-TAX NET PRESENT VALUE (\$1,000)= -4484
 AFTER-TAX ANNUAL EQUIVALENT COST (\$1,000) ...= -1244
 AFTER-TAX COST PER TON (\$)= -12.44
 BEFORE-TAX PRICE TO BE CHARGED (\$/TON)= 20.73

It should be noted that if the price to be charged is inputted to the developed model, the project becomes a revenue generating project, and its Net Present Value (NPV) becomes exactly equal to "0", securing a rate of return equal to the discount rate. For instance, in the truck example given in this section, the price to be charged was calculated to be \$20.73 per ton. This price was entered in the input data screen and the model reran. The resulting output file is shown in Table 11. As seen, the project becomes a revenue generating project, giving positive values in the first line of the table (\$2,073,000); and the NPV of the project was equal to "0", indicating a rate of return of 12%.

Table 11. Demonstration of revenue generating project when a price per ton is given to the economic evaluation model (Truck example)

BYPRODUCT TRANSPORTATION BY TRUCK SYSTEM

DISTANCE (MILES) ----- = 100
 PRODUCTION (TONS/YEAR) ----- = 100000
 MINIMUM REQUIRED RATE OF RETURN (%) ----- = 12
 EFFECTIVE TAX RATE (%) ----- = 40
 PRICE TO BE CHARGED (\$/TON) ----- = 20.73

Year	0	1	2	3	4	5
Revenue.....	0	2073	2073	2073	2073	2073
-Oper. Cost.....	0	-1708	-1708	-1708	-1708	-1708
-Depreciation...	0	-321	-492	-266	-156	-138
Taxable Income..	0	44	-127	99	209	227
-Tax.....	0	-18	51	-39	-84	-91
Net Income.....	0	27	-76	59	125	136
+Depreciation...	0	321	492	266	156	138
-Capital Cost...	-1442	0	0	0	0	0
Net Cash Flow...	-1442	347	416	326	281	274

CAPITAL GAIN (OR LOSS) COMPUTATION (\$1,000)

Salvage Value.....	640
Book Value.....	-69
Capital Gain (or Loss).....	571
Tax Liability.....	-229
After-Tax Capital Gain (or Loss).....	343
Book Value.....	69
After-Tax Cash Flow Due to Cap. Gain (or Loss)...	412

AFTER-TAX NET PRESENT VALUE (\$1,000)= -1
 AFTER-TAX ANNUAL EQUIVALENT COST (\$1,000) ...= -0

5.3 Capital cost of underground placement system

The research group who investigated the underground placement system developed a hydraulic and a pneumatic system. Both systems were demonstrated at the Peabody No. 10 mine near Pawnee, Illinois, during the summer of 1997.

In systems economic study, the capital costs of the placement systems are expressed as a function of the capacity (tph). The system capacity is obtained in the engineering design computation spreadsheet as a function of the annual CCB to be placed, number of shifts per day to place the CCB, and number of operating hours.

It is noted that the functions for capital costs are based on the costs incurred and experience gained during the demonstration of the developed technologies. Since these systems are not readily available and have to be custom-built, it is natural that any cost estimates from these functions must be treated with caution. Furthermore, the functions were obtained for capacity ranging from 50 tph to 100 tph for pneumatic system and 50 tph to 150 tph for the hydraulic system. Therefore, estimates will be valid only in this range.

Specifically, Equations 5.2 and 5.3 were obtained for the estimation of placement system capital cost.

- For the capital cost of the pneumatic placement system:

$$y = 153,333 - 200x + 6.67x^2 \quad \dots\dots\dots \text{Eq. (5.2)}$$

where:

y is the capital cost in \$
x is the system capacity in tph.

For example, a pneumatic placement system with 100-tph capacity will cost:

$$y = 153,333 - 200(100) + 6.67(100)^2 = \$200,000$$

- For the capital cost of the hydraulic placement system:

$$y = 16,667 + 5500x - 16.67x^2 \quad \dots\dots\dots \text{Eq. (5.3)}$$

where x and y are defined as in Eq. (5.2)

For example, a hydraulic placement system with 100- tph capacity will cost:

$$y = 16,667 + 5500(100) - 16.67(100)^2 = \$400,000$$