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DEVELOPMENT OF AN OPTIMAL STORAGE PLAN FOR A TYPICAL COAL MINE IN THE EASTERN POWDER RIVER BASIN

by

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ABSTRACT

The purpose of this thesis is to develop an optimal storage plan for a surface coal mine located in the Eastern Powder River Basin. This plan is developed for the silo type of storage and loadout facility for 2 scenarios: Scenario A with maximum annual output of 24 million tons per year and plant capacity of 6000 tons per hour; and Scenario B with maximum annual output of 12 million tons per year and plant capacity of 3000 tons per hour. Storage plans are developed for each of these scenarios by determining when the cost of providing storage is equal to the savings it will generate. A simulation model of the activities involved in the storage and loadout process is developed to generate information about costs which are incurred because storage is inadequate. These costs are labor and demurrage costs. At the point in time when the net present value of these accumulated costs are equal to the cost of a silo, the silo should be built. This break-even analysis is performed for each scenario, as well as an analysis which does not discount costs--the payback method. For Scenario A, the break-even analysis, discounting costs, recommends that additional silos be built in years 16 and 26, for a total of 3 silos. The payback method recommends that silos be built

in years 10, 16, 23 and 29, totaling 5 silos. For Scenario B, the discounted cost break-even analysis recommends that a silo be built in year 30, for a total of 2 silos, and the payback method recommends that silos be built in years 12, 21, and 29, for a total of 4 silos. These results suggest that, for Scenario A, the second silo be added between years 10 and 16, and the third, between years 16 and 26. For Scenario B, the results recommend the addition of a second silo between years 12 and 30. These results suggest that, based on the cost criteria used in this study, the mines in the Eastern Powder River Basin have overinvested in storage capacity.

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CHAPTER 1

INTRODUCTION

It has been estimated that the surface coal mines in the Powder River Basin are operating at 60% of their rated capacity, resulting in excess capacity of 40% in plant, storage, and loadout facilities (Office of Technology Assessment, 1981). During the 1970s when demand was high and cash flow plentiful, capital equipment was purchased in anticipation that the demand for coal would remain at an annual growth rate of 7%. When the demand rate fell in the early 1980s, the mines reduced the production rates and began operating closer to their marginal cost because they had overinvested in capital.

Capital investment can occur within several different areas of a mine and can have different short-term and long-term effects on a mine's rate of return, depending on when and how much capital is invested. This study will determine when and how much capital to invest in storage and loadout facilities at a typical surface coal mine located in the Eastern Powder River Basin by developing an optimal storage plan for the life of a mine. Only the silo type of storage facility will be considered in this thesis. The

storage plan will determine how many silos should be constructed and calculate the optimal point in time for construction using net present value criteria.

For the purpose of this study, surface coal mining can be divided into 3 subsystems: production in the pit and at the plant, storage and loadout, and transportation, as depicted in Figure 1.1 (Bradley, et al., n.d.).

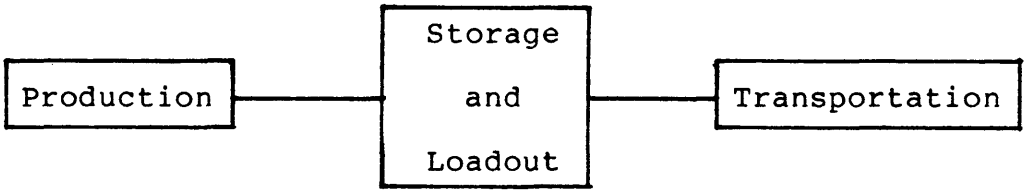

Figure 1.1
Subsystems of a Surface Coal Mine

The storage and loadout subsystem is driven by the production and transportation subsystems which, in turn, are dependent on the demand for coal. Because the successful functioning of this system is affected by the demand rate for coal, it is necessary to construct different scenarios with different annual production rates, growth rates, and

plant capacities. Two different scenarios of surface coal mines in the Eastern Powder River Basin will be created from historical production information. Scenario "A" reaches a maximum annual output of 24 million tons per year (tpy) with a large plant capacity of 6000 tons per hour (tph). Scenario "B's" maximum annual output is 12 million tpy with a plant capacity of 3000 tph. In both cases, the first 8 years are characterized by highly variable growth rates in production as contracts are acquired. In the later years, because there is no historical information, this growth rate will be assumed to be constant until the maximum output is reached. Performing this analysis on 2 separate cases will 1) demonstrate how the Eastern Powder River Basin may have overinvested in capital in the 1970s, 2) establish the critical points in time for making decisions regarding the addition of storage and loadout facilities, and 3) provide management with criteria and additional tools to make similar but more informed decisions in the future.

One of the key factors which affects the decision of when to build additional storage is the stochastic nature of train arrivals. If management knew precisely when to expect a train to arrive, they could plan to have coal available in the silo so that the trains don't wait and demurrage is not incurred, and they could schedule labor crews accordingly.

Management does not know this, however, and the nature of the train arrivals affects demurrage and labor costs because train arrival times are variable. Neither the exact time of arrival of a particular train at the mine nor the number of train arrivals in any period of time can be determined precisely because of their stochastic nature.

The nature of the train arrivals can cause problems on the weekends if crews are not scheduled to work. The mines typically operate on an 8-3-5 schedule (i.e., 8 hours per day, 3 shifts per day, 5 days per week). Therefore, if the trains arriving on the weekends demand more coal than the storage facilities can supply, additional work shifts must be scheduled on the weekends with premium wages paid to laborers.

If, on the other hand, labor crews are not called out on the weekends, and the trains demand more coal than can be supplied, the trains must wait until labor crews arrive. The mine will then incur demurrage costs for each train which waits longer than 4 hours. This cost can be substantial, as much as $400 per hour. Even so, it may be cheaper to incur demurrage than to pay premium wages to the workers and incur the intangible costs associated with waiting trains. To decide which management action is least costly, scheduling the work crews for overtime or letting

the trains wait, is difficult for 2 reasons:

1. Labor costs and demurrage costs depend on the behavior of two stochastic variables--train arrival rates and the number of train arrivals.
2. Intangible costs are present, as discussed in the following paragraph.

If management chooses to incur labor costs, then the morale of the work force may decline, an intangible cost. Even though the workers receive premium wages for working on the weekends, they may resist being placed on standby for an entire weekend. Also, if the labor force is called to work, they are pressured to work harder and faster than usual to load waiting trains. After the trains have been loaded, the workers are left with little to do during the remainder of the shift. The "on again, off again" nature of such working conditions can create morale problems.

If management decides to incur the demurrage cost instead of scheduling overtime, it may lose the goodwill of the utility as well as the contract. If trains have to wait at the mine, then cycle time (the travel time from the utility to the mine and back to the utility) increases. If the increase is substantial, the utility may be forced to buy another 100-unit coal train, since the existing ones cannot arrive at the utility in time to deliver enough coal

to meet its demands. The coal company may lose the utility as a customer and may gain a reputation as an unreliable supplier, and thus be placed at a disadvantage in bidding on new contracts.

To avoid such consequences it is important for management to be able to plan facilities which can handle anticipated demand. This study will develop the methodology which will enable management to plan for storage and loadout facilities. This methodology will simulate the activities in the storage and loadout subsystem subject to the constraints imposed by the production subsystem and the transportation subsystem. The information obtained from this simulation will be used in a break-even analysis to determine when to construct additional storage facilities. The storage facility should be in service when the cost of providing storage is equal to the savings it will generate. The cost of providing additional storage is the capital cost, including the costs for design, engineering, construction, and labor. Savings to be gained by providing additional storage are in 1) labor costs, 2) demurrage costs, and 3) intangible costs. The break-even analysis will be performed using net present value analysis.

In addition to developing an optimal storage plan, this thesis will provide management with other decision tools

which might be used for either short-term or long-term planning. This technique will estimate the cost of train delays in terms of lost revenues.

This thesis will be organized as follows.

Chapter 2 will review literature related to coal storage at surface coal mines. Although no published articles specifically address the problem of developing an optimal storage plan for the life of a mine, several articles discuss storage problems and issues resulting from shift schedules, drying facilities, and train schedules.

The economic theory for determining the least-cost storage plan will be presented in Chapter 3. The concepts of input substitution and resource allocation will be presented followed by an explanation of the economic implications of the least-cost allocation of resources. Finally, the theory of aggregate production planning will be discussed.

Chapter 4 will present the methodology and analysis required to develop an optimal storage plan. It will present the rationale for using Scenarios A and B as models and analyze the available data on train arrivals per day to detect seasonality and establish probability distributions. The assumptions supporting this rationale and analysis will be presented, as well as the assumptions used in the

simulation models. The simulation models which will be used to simulate the activities of storing and loading coal will be discussed as well as the output from the simulation models. Chapter 4 will show how this output will be used in deriving the costs for labor and demurrage. Finally, this chapter develops the break-even analysis which will be used to determine when additional silos should be built.

Chapter 5 discusses the caveats in using the results of this study. It also shows how the model built for this study would be changed to accommodate different assumptions required for other scenarios.

Chapter 6 summarizes, presents results, draws conclusions, and makes recommendations for future research.

Appendix 1 shows additional costs which might be generated by incurring demurrage. Appendix 1 also shows different ways of calculating demurrage. Appendixes 2 and 3 contain program listings for the simulation models.

CHAPTER 2

LITERATURE REVIEW

The number of published articles dealing with the optimum amount of coal storage is limited. However, there were three sources which yielded pertinent literature: universities, a coal company located in the Powder River Basin, and professional and trade journals. The major criticism of all the literature is that none based their decisions on cost.

2.1 Univeristy Studies

2.1.1 University of Wyoming Study

Sizing Storage Facilities for Open Pit Coal Mines (Bradley, Taylor, and Gray, n. d.) develops a general procedure for determining the required storage capacity for open pit coal mines. The purpose of the University of Wyoming study is quite different from that of this thesis in that it is more concerned with a static, rather than dynamic model, and decisions to add more facilities are based on design variables rather than cost. Nonetheless, some of the

concepts and techniques are applicable to this thesis.

To determine the capacity, working stock and safety stock requirements are estimated using a combination of deterministic models and simulation models. This procedure for sizing storage facilities is then illustrated using data representative of a mine in the Eastern Powder River Basin.

The procedure consists of the following steps:

1. Calculate the minimum production rates and minimum storage capacity from the deterministic model. This provides lower bound estimates for the parameters of the simulation models.
2. Using the simulation models, develop a base case for storage facilities, loading tracks, and production rates.
3. Conduct a sensitivity analysis on the base case.

Step 1 calculates the minimum storage capacity required for working stock, using the demand rate, the loading rate per track, the unit train capacity, and assay time. The demand rate is expressed in trains per day and assay time is one hour. These paramaters remain unchanged and from these parameters, the minimum storage capacity is calculated, and the minimum number of silos determined. This deterministic model establishes the primary design variables which will be

analyzed in the simulation model: the number of loading tracks, storage capacity, production rates (tons/hour), and train fill rates.

In Step 2, the simulation model considers the stochastic nature of train arrivals. When the number of cycling trains approaches 30 to 40, data indicates that the times between arrivals can be approximated by a negative exponential density function. The distribution of train arrivals were approximated by simulating the cycling of a fixed number of trains between the mine and customers. The other alternative was to generate train arrivals according to a probability distribution, but it proved to be less accurate when the demand created by the train arrival rate approached the mine production rate. Step 2 calculates the wait times for different designs, varying the number of tracks, silos, and hourly production rates.

The sensitivity analysis was conducted in Step 3 and additional variables analyzed, making adjustments to parameters to obtain a more suitable design. The additional design variables included were the time between equipment failures (reliability of the plant and equipment), mean repair time, and assay time. The results of this analysis were intuitive: Increasing failure rates, repair time, and assay time increases the holding time in the silos and the

storage requirements.

In the example application, the authors assumed that the mine operates 365 days per year, 24 hours per day, which may be an unrealistic assumption. In developing the base case, "the model contained logic for scheduling weekend shifts." Weekend shifts are already calculated into the deterministic model, so the integrity of the model may be questionable. However, the authors further state, "This model was validated against 1981 operating data for an actual mine."

The Wyoming study is useful in determing the optimal configuration of storage and loadout facilities which keep trains waiting the least amount of time. If costs, markets, and the dynamics of a coal mine are addressed, however, the study is of little use. Nonetheless, the study must be praised for its application of Simulation Language for Alternative Modeling (SLAM). The code is sophisticated, impressive, and valuable in developing the code for this thesis. It must also be praised for applying the concepts of working stock and safety stock to a mining situation instead of its usual application to manufacturing. The major shortcoming of this study was that it did not calculate costs for different alternatives, but states that "the costs of alternative configurations are obtained using standard cost estimating techniques." To do so is not a simple

matter. The article was helpful in understanding the activities involved in storage and loadout from a simulation perspective and in developing the SLAM coding for these activities.

2.1.2 School of Mines Study

The "Preliminary Study of Storage and Loadout Facilities at Mobil's Caballo Rojo Mine" (Durham and Gwinn, 1982) is an unpublished study which was done at the Colorado School of Mines. The objective of this report was to determine when additional storage and loadout facilities would be required at the Caballo Rojo mine and to estimate demurrage hours in the first production year. To accomplish this task, the loadout and storage facilities were simulated using the SLAM simulation package. Several scenarios were run using different production rates and different contract obligations. The objective of this report is similar to the objective of this thesis, but differs in that it is only looking at one year of production. The assumptions of the Durham and Gwinn report differ from those of this study as detailed below and therefore, is not particularly useful in the development of ideas for this study.

The assumptions of the Durham and Gwinn report are the following:

1. The work schedule used is 9-1-5, i.e., 9 hours per day, 1 shift per day, 5 days per week. No overtime is assumed.
2. No upper limit is established for an acceptable level of demurrage.
3. No costs are associated with the various alternatives.

This report ignores the major problems associated with developing a plan for storage facilities: the cost of providing additional storage, additional labor cost if storage capacity is insufficient, and the establishment of acceptable levels of demurrage.

2.2 Coal Company Studies

A second source of information is proprietary information from a coal company located in the Powder River Basin. They did four studies which examined the storage situation at their mine.

2.2.1 The First Study

The objective of the first study was to determine when additional storage capacity would be required if the mine and plant shift schedules are varied. First, a reference case is developed on which to base the analysis. In this base case the mine operates on an 8-2-5 schedule with overtime, ships 1.5 million tons per year, and has 2 silos for storage. A unit train simulation is also included. This study, however, does not clarify the methodology used in the simulation and does not state whether the stochastic nature of train arrivals is considered.

A "cost definition" is provided which states that annual cost is the sum of 5 other component costs: annual demurrage cost, annual mine shutdown costs, annual overtime costs, incremental annual operating costs (i.e., over the reference case), and incremental annual capital costs. The cost definition is not explicit. For example, it is not stated whether this cost definition is the cost incurred by the mine due to insufficient storage capacity or the cost of new storage, or both. It appears to be both. Neither are the cost components fully defined, and the inclusion of one in particular may not be justfied: mine shutdown costs. If the silos are full, attention can be given to overburden

removal instead of shutting down the mine. If, after removing all the overburden that is feasible (it is desirable to avoid double-handling), the silos are still full, then perhaps the mine could reduce its rate of production. Also, the trains will usually arrive soon enough to drain some of the coal from the silos, and it is doubtful that the coal will remain in the silos very long before it is discharged. If a mine must shut down because the silos are full, this may be more of a function of mine management than storage capacity and may not be justifiably attributed to insufficient storage capacity.

Another error may exist in the calculation of overtime costs. Since overtime costs are built into the reference case, the overtime costs in the "cost definition" should be incremental overtime costs, those costs greater than the planned expenditures of the reference case. Since the overtime cost component is not clearly defined, it cannot be determined whether this particular calculation is in error.

Neither is the operating cost component clearly defined. If it is the cost of operating a new silo, then its inclusion is correct. If it is the cost of operating the mine and plant equipment to keep up with the demands of the coal trains before new storage is built, then it should be omitted. For example, if the mine is operating overtime for

this latter reason, then the pit equipment is mining and processing coal which would already have been mined and processed if the storage capacity had been sufficient. On the other hand, if storage is sufficient to meet the demand, but more trains than expected arrive, then the equipment is operating to mine and process coal which would have been mined and processed in the near future anyway. In either of these 2 situations, the only cost incurred which can be attributed to insufficient storage capacity is the incremental labor cost.

After establishing a reference case, the shipment levels, mine schedule, and storage capacity are varied to determine the least-cost alternative. The least-cost alternative is not explicitly identified but inferred by looking at several graphs. However, each of the 4 graphs shows a different least-cost alternative and has no explanation of the results. This haphazard solution may have been caused by simultaneously changing the 3 variables--shipment levels, mine schedules, and storage capacity--instead of changing one at a time and holding the others constant. The final recommendation advocates 3 different shift schedules for 3 different shipment levels. No storage plan was recommended or costs calculated.

The major shortcoming of this first study is that it

does not meet its stated objective--to determine when additional storage capacity would be required if the mine and plant shift schedules were varied. In addition, it is impossible to determine how the individual cost components were calculated. Therefore, this study is of little use in developing the methodology for this thesis.

2.2.2 The Second Study

A second study done by the coal company simulated train loadouts to determine storage requirements for various schedules. These simulations were run for 5.6, 8, and 12 million tons per year. The results indicate that for a specific level of output, the more coverage which is provided by the mine schedule (i.e., working on the weekends or on overtime), the less storage required, an intuitive result. In the assumptions only one loadout loop was included in the lower shipment levels. In a critique of this article done by the same coal company, the author states that the assumption of only one loadout loop is unrealistic since it is more likely that there will be two loadout loops for this particular mine.

The results of this study show the demurrage hours per year, the utilization of storage capacity, and the train

service time for various shipment levels, storage capacities, and mine schedules. Also included are the probability distributions of train arrivals on the weekends for various shipment levels. These are interesting results, but the study concludes at this point. No recommendations are made which suggest the best plan for storage facilities. The reason for this omission is probably due to the fact that the one piece of information which is vital to making this type of decision is missing--the cost for each of the 34 plans.

2.2.3 The Third Study

The third study done by this coal company assessed the impact of using one of the existing silos for coal drying tests. By dedicating a silo to coal drying, the study showed increased demurrage costs, additional mine shut downs due to full storage, and additional overtime costs. The results show that these additional costs are less than the cost of an additional silo, and it is therefore recommended that additional silo storage not be built. To minimize the cost of dedicating one silo to coal drying, the study recommends negotiations with Burlington Northern to "arrange for more flexible train scheduling and application of

demurrage charges."

This study does not include capital costs and operating costs since "case costs are only used in comparison of cases with the same shift schedules and volume levels." This rationale for excluding these costs is unclear, and excluding these costs may be unrealistic.

This study incorrectly calculates overtime costs by equating this cost to hourly mine shut-down costs multiplied by a "pay factor" of 1.50 or 2.00. Not considering the dubious nature of shutdown costs, the pay factor is wrong. The pay factor should be 0.50 or 1.00, the incremental labor cost. If labor crews had not been called out on the weekends and paid overtime, they would have mined the coal anyway, but at the regular rate of pay. Therefore, the cost of labor due to insufficient storage is the difference between the regular rate of pay and premium wages. Also, it is unclear why mine shut-down costs were included in this calculation. It seems that a better method of calculating overtime cost would be to determine the average number of workers who would be working overtime and multiply this number times the incremental difference between the regular rate of pay and the overtime rate of pay.

If the coal drying tests last 2 years, the author states that the savings generated by adding silos will be twice the

savings realized in 1 year, which is incorrect. The savings must be discounted. Therefore, the entire cost analysis is wrong because the costs and savings are not discounted. In addition, the author does not state how many years are spanned by the cost analysis for each of the cases presented. Although this study appeared to develop the correct methodology, its results are erroneous because the time value of money was not considered.

2.2.4 The Fourth Study

This final study used a break-even approach to find when to build additional storage for 2 cases: the construction of one silo or the construction of 2 silos. Any cases other than these two can be evaluated "by ratioing the new capital and an original case." The rationale supporting this statement is unclear because all details of the analysis are omitted. Also it is not stated whether labor cost, train arrivals, and demurrage are taken into account. This fourth study is very brief, and it is therefore impossible to decipher what evaluation techniques and details might have been used.

2.3 Professional and Trade Journals

The final source of literature is the professional and trade journals. The periodical which contained the most relevant references was the Applied Science and Technology Index. This periodical was searched from January 1972 through April 1984 and contained numerous references to Coal Age, Mining Congress Journal, and Mining Engineering. This search resulted in the discovery of one article related to this thesis topic. Besides this index, two others were used: Operations Research/Management Science Service from 1971 through 1977, and Simulation, from 1974 through 1977. Neither of these yielded pertinent information.

Although this study is not considering barn-type storage as an alternative to silos, a brief discussion of the decision criteria in choosing one type of storage over another is appropriate, since it may be useful information for the reader and for those who intend to do further research in this area. One article, "Silo vs. Barn Type Storage for Coal" (Mueller, 1977) presented some of these decision criteria and provided a more qualitative than quantitative description of these two types of storage. It showed plan and sectional drawings of each and also gave the following guidelines for determining which type of

storage facility to build.

1. The storage tonnage required, depending on the mine production rate.
2. The shipping rate required, based on average tons per day to meet contract obligations.
3. The railroad schedule.
4. Owner preference. The author states, "Many clients have their minds made up and are not interested in facts."
5. Soil conditions. Soil conditions may be unsatisfactory for particular types of storage. In some cases it may be more economically feasible to build silos, but a barn must be built instead because of soil conditions.
6. The rate of future expansion.
7. Available capital.
8. Sampling. The train can be sampled in a barn-type system, but not in a silo storage system.
9. Blending.

This article also provides some general rules of thumb for the choice of type of storage. It states that for storage requirements of less than 50,000 tons, silo capital investment is less than for barn-type storage. For the

50,000 ton range, the silo and the barn-type storage with a separate train loadout facility require about the same capital investment. For tonnages greater than 50,000, the barn storage is favored, requiring less capital investment than the silos. The article further states that for tonnages in the range of 25,000 tons, barn storage is competitive "unless blending is a consideration." Also, the operating cost for the barn storage is higher than silo storage, approaching 5%, mainly due to maintenance cost.

This literature review uncovered several interesting articles which were helpful in developing the methodology for this thesis, especially the study from the University of Wyoming. Nonetheless, all of the articles developed a methodology and calculated results apparently without considering the basis for the methodology--the economic theory.

The economic theory serves as a guide to the analyst in the process of developing the methodology and applying it. The economic theory which is appropriate for the coal storage problem consists of the general theories of input substitution and resource allocation and the more applicable theory of production planning.

CHAPTER 3

ECONOMIC THEORIES OF INPUT SUBSTITUTION, RESOURCE ALLOCATION, AND PRODUCTION PLANNING

This chapter describes the theory which will be used to develop a methodology for determining the capacity and timing of the construction of storage facilities. The general theory will be presented first, followed by economic theory which is directly applicable to solving the questions posed in this thesis. This economic theory also provides guidelines for aggregate production planning. First, the theories of input substitution and optimal allocation of resources will be presented.

3.1 Input Substitution and Optimal Resource Allocation

Different combinations of inputs can produce a given level of output. In the case of storage, capital investment and labor can be combined in different ways so that output remains constant, yet demurrage and overtime costs vary. The rate at which one input can be substituted for another to maintain constant output is important. Equally important is the proportionate change in the input ratio caused by a

change in the rate of substitution. The theoretical tool which measures this rate of input substitution and changes in this rate is the marginal rate of technical substitution. The theory of the marginal rate of technical substitution is essential to determine an optimal way in which resources should be combined.

The objective of determining the optimal input combination is to minimize cost subject to a given output. For example, if the quantity of labor and capital are denoted by L and K, respectively, and their unit prices by w and r, then the total cost C of any volume of K and L is $C = rK + wL$. If an amount C^* is to be spent, different combinations of labor and capital are given by

$$K = C^*/r - wL/r.$$

This equation represents an isocost curve. The following numerical example illustrates this concept.

If capital costs are \$1500 per unit (r=1500) and labor cost is \$3000 per labor-year (w=3000) and a total of \$15,000 will be spent for inputs, then the following combinations are possible:

$$\$15{,}000 = \$1500K + \$3000L$$

or

$$K = 10 - 2L.$$

If \$20,000 will be spent, the combination that can be purchased is \$20,000 = \$1500K + \$3000L or

$$K = 20 - 2L.$$

These 2 isocost curves are shown in Figure 3.1. The isocost curves show the various combinations of inputs which may be purchased for a stipulated amount. A producer will seek the lowest feasible isocost curve in order to minimize total cost for a given output. This can be done by allocating an optimal combination of input resources, capital and labor toward production. The graphical representation of this problem is presented in Figure 3.2.

Isoquant I represents the required level of output and C_1, C_2, and C_3 isocost curves. Note that C_1 is not feasible for output I. At points R and S, output I can be produced for a cost of C_3. However, the same level of output can be produced at point Q for less cost than at either of the points R or S. Equilibrium is obtained at Q, the point of tangency between the isocost curve and the isoquant. This is

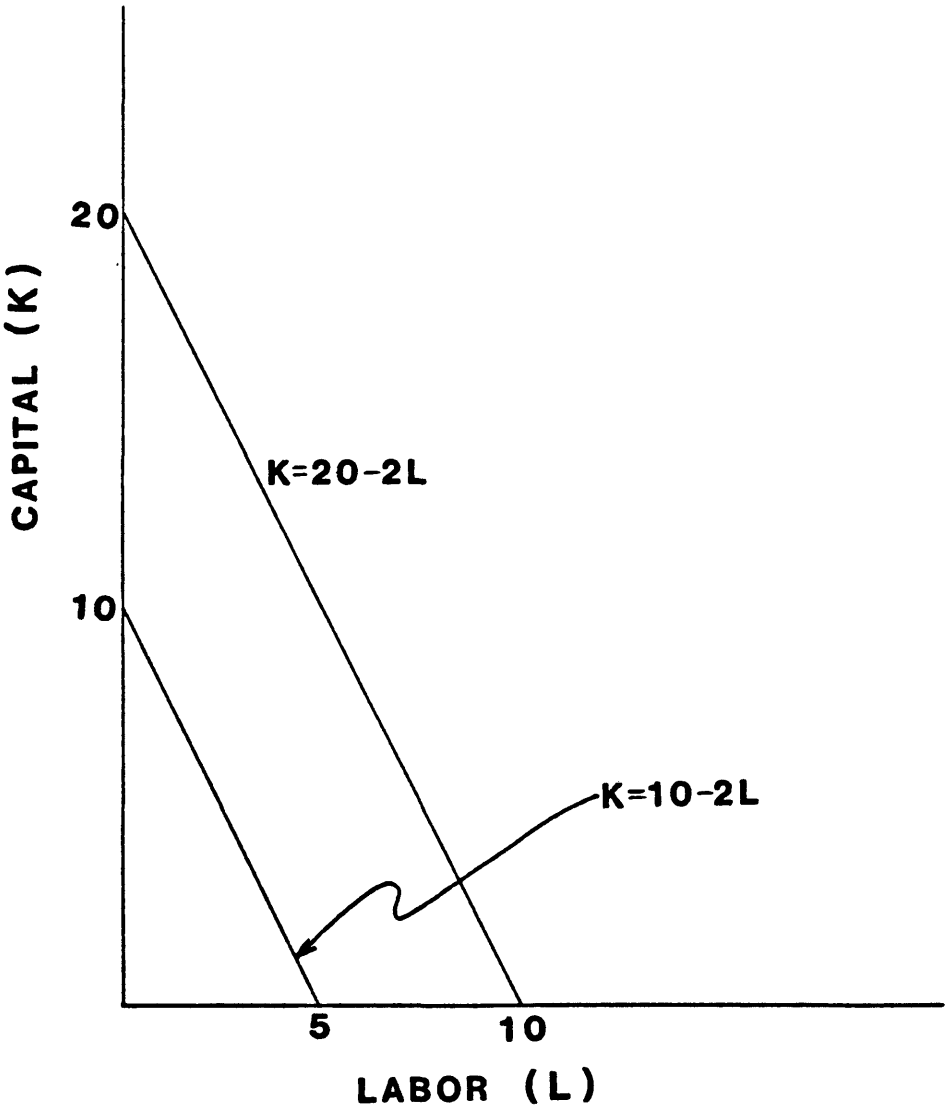

Figure 3.1

Isocost Curves

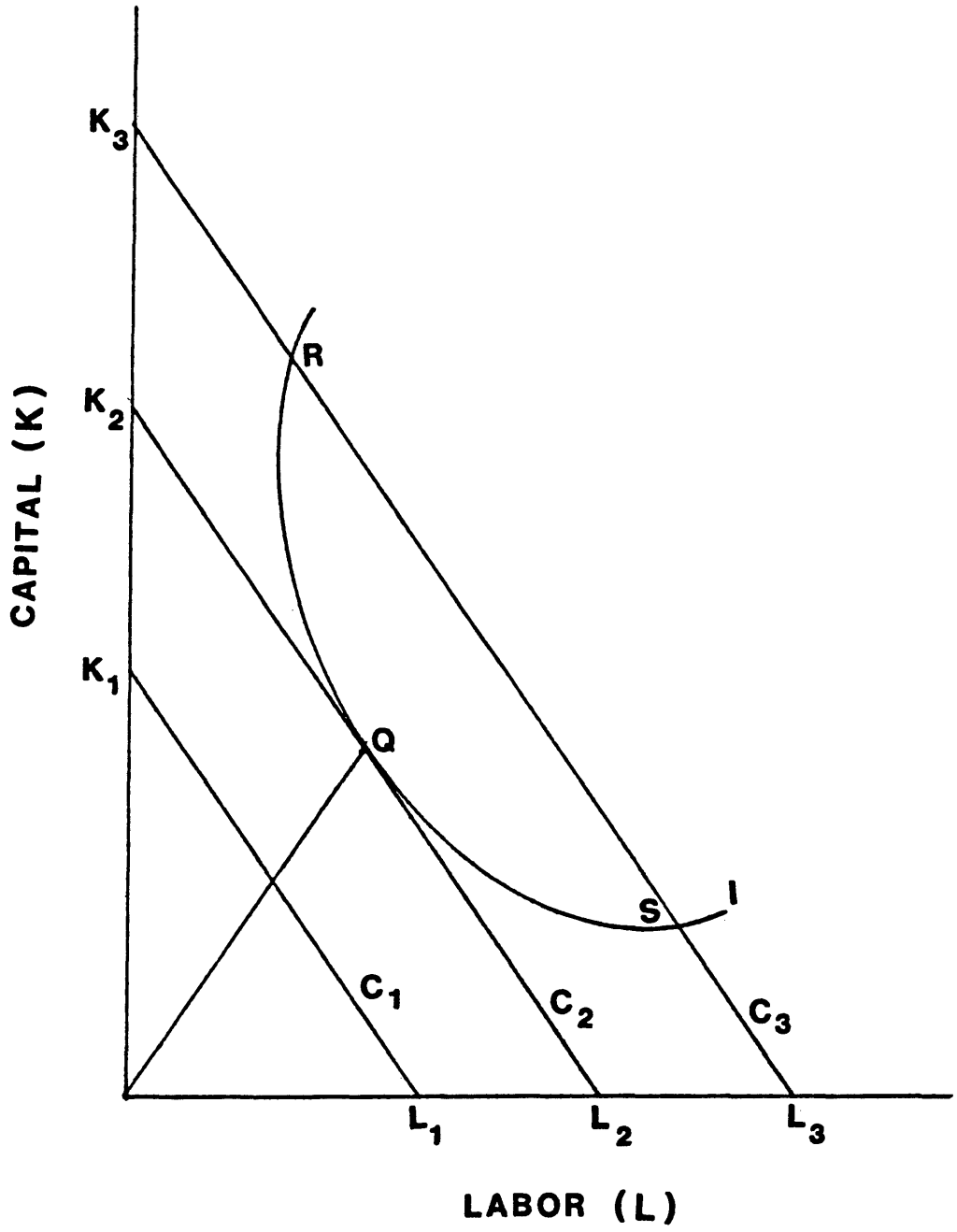

Figure 3.2

Optimal Combination of Resources

the point at which the marginal rate of technical substitution of capital for labor is equal to the ratio of the price of labor to the price of capital.

If a mine decreases costs for a given level of output, it is moving closer to this "ideal" point and is also moving to a lower isocost curve. If total cost can be minimized by operating on the lowest feasible isocost curve, then the producer is in a much better market position. Operating on a lower isocost curve is equivalent to reducing average total costs. The advantages of reducing average total costs are illustrated in Figure 3.3. If average total cost is reduced, then marginal cost is also reduced, and profits increased (or losses decreased if the price falls below the average total cost). If the average total cost decreases from ATC_0 to ATC_1, marginal cost will be reduced from MC_0 to MC_1. Such changes in these costs result in increased output from Q_0 to Q_1 and an increase in profits represented by the area FEDABC.

In the process of reducing average total costs, average variable costs may also be reduced. It is desirable for the mine to reduce its average variable costs because the mine can then operate at even lower prices so long as total revenue exceeds total variable cost of production at the equilibrium output. This is illustrated in Figure 3.4. If

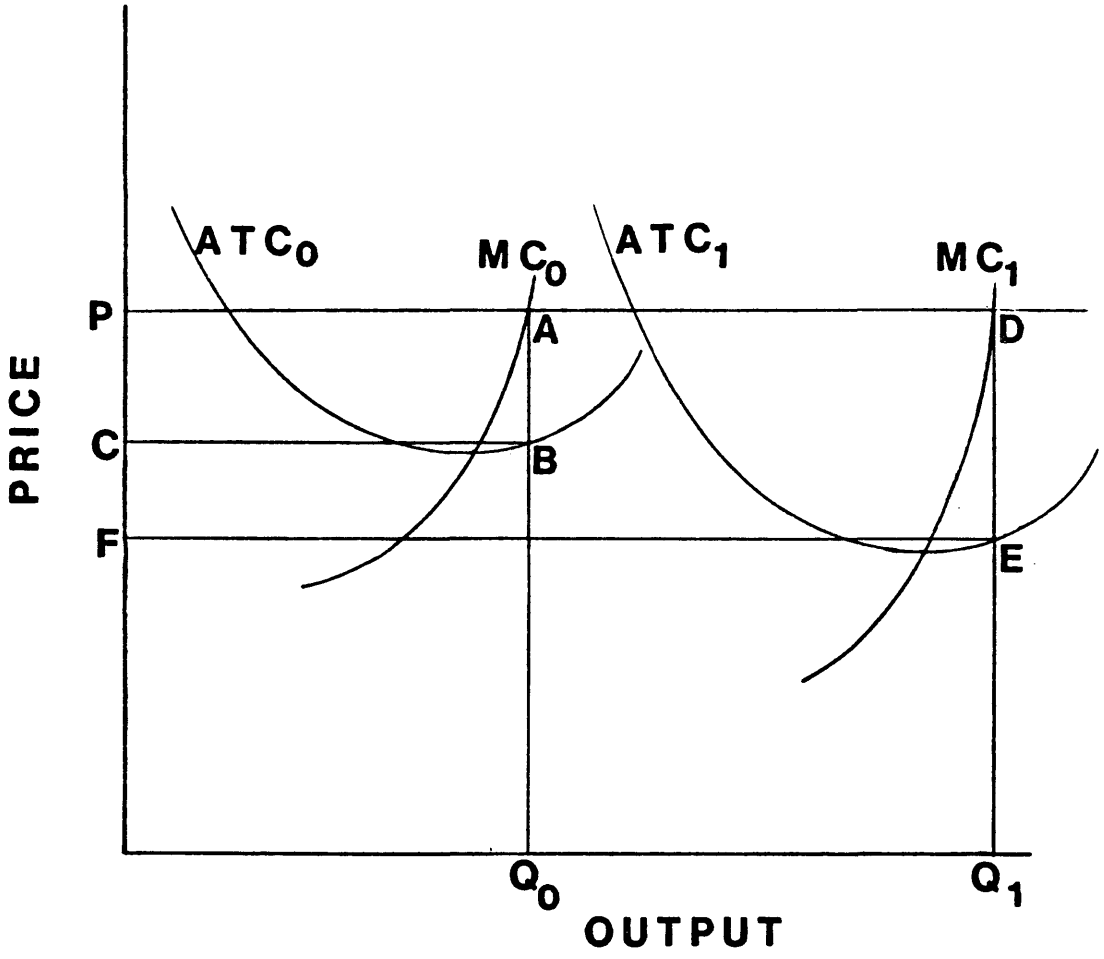

Figure 3.3

Effects of Changes in Cost on Profit and Output

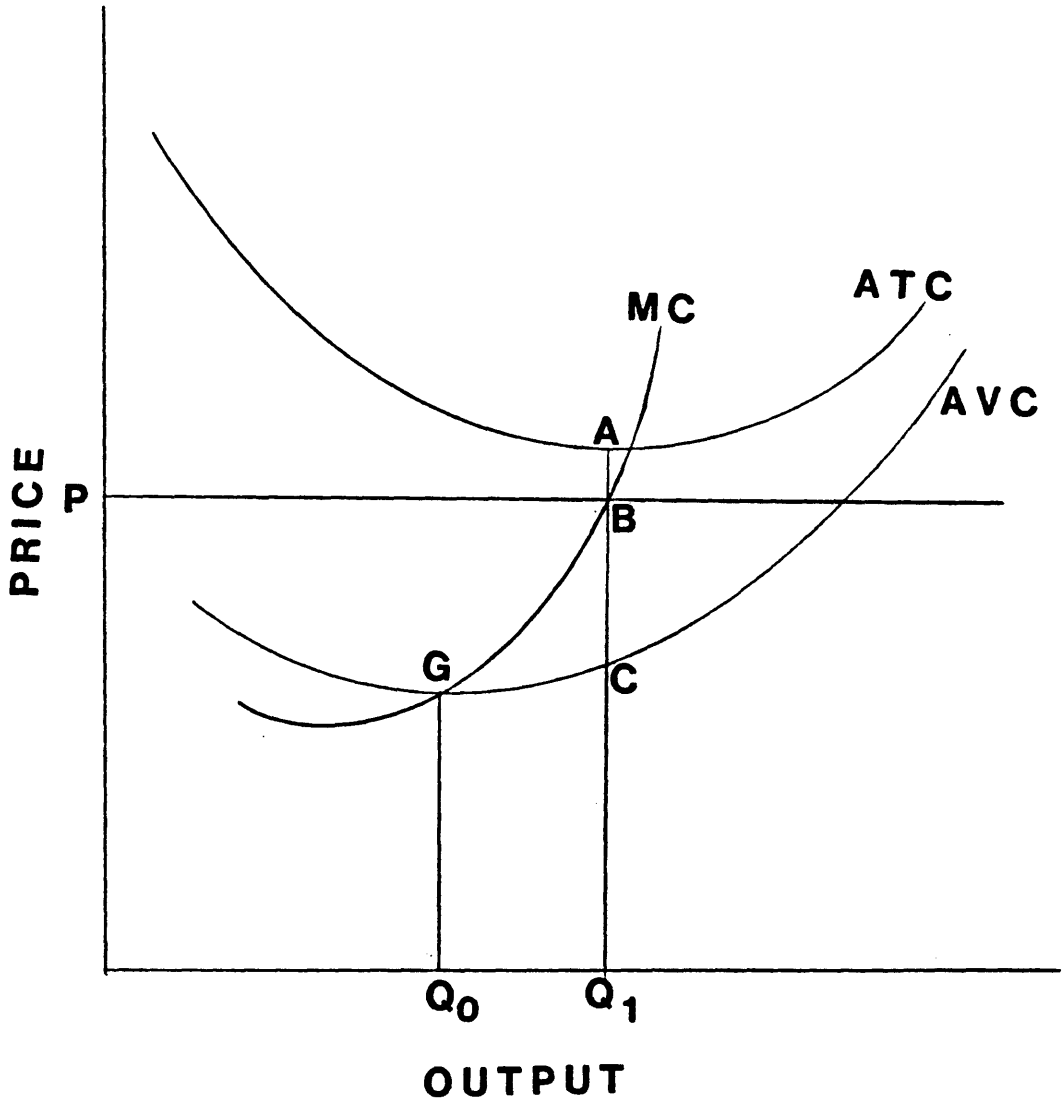

Figure 3.4

Effect of Average Variable Costs on Revenues

price = P then equilibrium is obtained at output Q_1 and the mine incurs a loss of AB dollars per unit. However, variable costs are covered and there is an excess of BC dollars per unit which can be applied to fixed costs. If price drops below Q_0G, the equilibrium output would be zero and the mine would no longer operate since the variable costs would no longer be covered. To produce at any price below Q_0G would mean that the mine would not only be unable to pay fixed costs, but it would also lose an amount per unit equal to the difference between the marginal cost and average variable cost curves. Therefore, if a mine can reduce its average variable cost, it will obtain greater profits or incur less loss and be able to continue to operate as prices drop, retaining a competitive position in the market place.

This economic theory shows why it is important for a mine to keep its average total costs as low as possible. Minimizing average total costs can be achieved if mine management knows when to invest in capital as labor and demurrage costs become too high. Yet, the investment should not be made too soon because the mine may unnecessarily drive up its average total costs and lose the use of capital which might have been used elsewhere. If the investment is made too late, the mine may incur large labor and demurrage

costs, driving up average total costs and intangible costs.

3.2 Aggregate Production Planning

The advantages of reducing costs should be apparent. There are many aspects of surface coal mining to which an analysis for determining the least-cost operation could be applied: the operation of the pit equipment, the extraction rates, the capacity and operation of the plant, etc. The primary aspect considered in this thesis is coal storage and loadout.

This problem is essentially an inventory problem which involves tradeoffs between capital and labor. The problem of deciding how much storage to build and when to build it is part of what might be called an "aggregate production planning decision" (Peterson and Silver, 1979). The aggregate planning model presented by Peterson and Silver assumes a forecast of demand for a product, coal in this case, and then determines for each period:

1. The size of the work force, W_t
2. The rate of production, P_t
3. The quantity shipped, S_t

These decision variables can be determined by minimizing the following cost components:

1. The cost of regular payroll and overtime
2. The cost of changing production rates
3. The cost of carrying inventory
4. The cost of shortages resulting from not meeting demand

This model must be modified before it can be applied to solve the questions posed by the coal storage problem. In particular, the decision variables and cost components must be slightly modified. The production planning model appropriate for this thesis will determine when the storage facility should be built given the annual rate of production.

The cost components will be defined as

1. The incremental labor cost
2. The cost of carrying inventory
3. The cost of demurrage
4. The capital cost of storage

Notice that the first decision variable of Peterson and Silver, the size of the work force, has been omitted. It will be implied by the results of the thesis but not expressly determined. Because the incremental labor costs of adopting different alternatives will be calculated, this cost (or savings) of each alternative will imply the incremental differences in the work force required by each

alternative. In addition, one other decision variable needs to be included in the model: the time at which the storage capacity should be built.

The cost components need only be altered slightly. The first component should be redefined as the incremental labor cost, which will usually be in the form of overtime costs. Note that overtime costs rise sharply at higher levels of overtime because the efficiency of the workers decreases as they work longer hours, resulting in lowered productivity (Peterson and Silver, 1979). This is depicted in Figure 3.5.

The second cost component of Peterson and Silver's model, the cost of changing production rates, has been omitted. Ths cost of changing production rates over the life of the mine will be the same for each storage alternative and in comparing each alternative, it will be invariant.

The third cost component, the cost of carrying inventory, is made up of 2 types of costs:

1. Operating cost, or the cost of running the storage facility
2. Opportunity cost, or the cost of tying up capital that could be used elsewhere if inventory was not needed

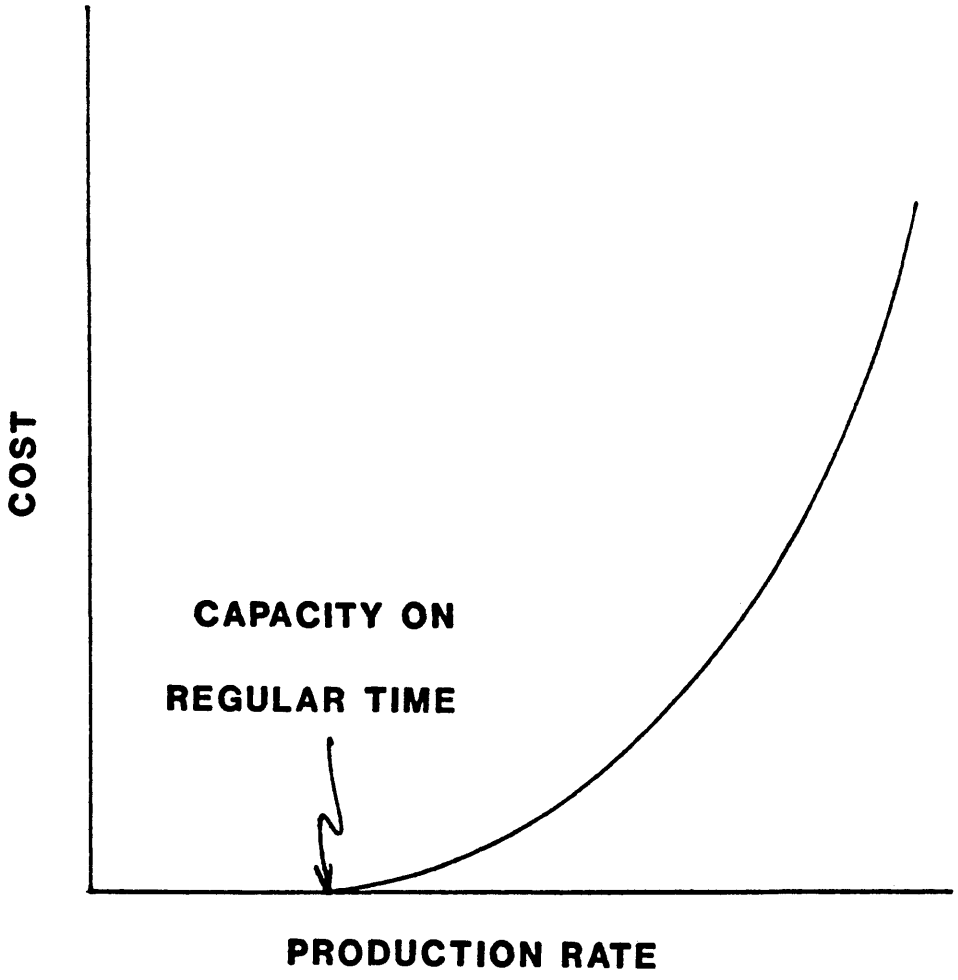

Figure 3.5

Typical Shape of Overtime Costs

for a Given Work Force Size

Opportunity cost would be incurred if, for example, the predicted demand was higher than the actual demand and a mine had built facilities based on the higher demand rate, resulting in excess capacity. This cost will not be used in the break-even analysis, but could be used to calculate the cost of building too many silos in the Eastern Powder River Basin.

The fourth cost component of Peterson and Silver's model, the cost of insufficient capacity in the short run, is either demurrage cost, labor cost, or both, depending on the action chosen by management. Also, one last cost component needs to be added: the capital cost of a storage facility.

This production planning model can be directly tied to the general theory of input substitution and the optimal allocation of resources. Recall Figure 3.2 which showed the different isocost curves for a given level of production. The vertical axis which represents capital is composed of the cost of carrying inventory and the capital cost of storage. The horizontal axis which represents labor, consists of the incremental cost of labor. The production planning model is more refined and applicable than the general theory of optimal resource allocation and input substitution.

The production planning model will use the cost components as criteria for determining when to build storage. When the incremental labor cost and the demurrage cost are equal to the capital cost and operating cost of storage, the storage should be built.

To calculate labor and demurrage costs, simulations using SLAM will be used. The simulations will be run for different production rates and storage capacities as the mine increases production. A break-even analysis will then be performed taking into account the time value of money to determine when the labor and demurrage costs are equal to the cost of the silo. It is feasible that a silo may be required to be built when labor and demurrage costs are less than the cost of a silo because the demurrage costs may become too high, rising above the maximum acceptable level.

Chapter 3 has presented the general economic theory relevant to production and inventory planning and has briefly explained how the production planning model will be used to establish an optimal storage plan for the life of a surface coal mine. Chapter 4 presents the detailed methodology and analysis for applying the production planning model so that an answer can be provided for the major question posed by this thesis: What is an optimal

storage plan for a surface coal mine in the Eastern Powder River Basin?

CHAPTER 4

METHODOLOGY AND ANALYSIS

This chapter will discuss the methods and analyses used to determine an optimal storage plan for the life of a mine. An overview of the methodology is first presented, followed by more detailed presentations in each section.

Figure 4.1 presents the overview of the methodology. The annual production rate, from Scenarios A and B, will determine the number of train arrivals per year at the mine. Given the number of train arrivals per year and the distribution of train arrivals per day (discussed in sections 4.2 and 4.3), the simulation model simulates the operation of the train loading system for 1 year, calculating weekend labor hours for the train loading crews and silo crews as well as demurrage hours. The hourly incremental labor costs and demurrage costs are calculated and the total annual cost of overtime labor and demurrage can be determined. This information is then used in a break-even analysis to develop a storage plan for the mine which uses net present value techniques to determine when the additional silos should be built. When the discounted incremental weekend labor and demurrage costs are equal to

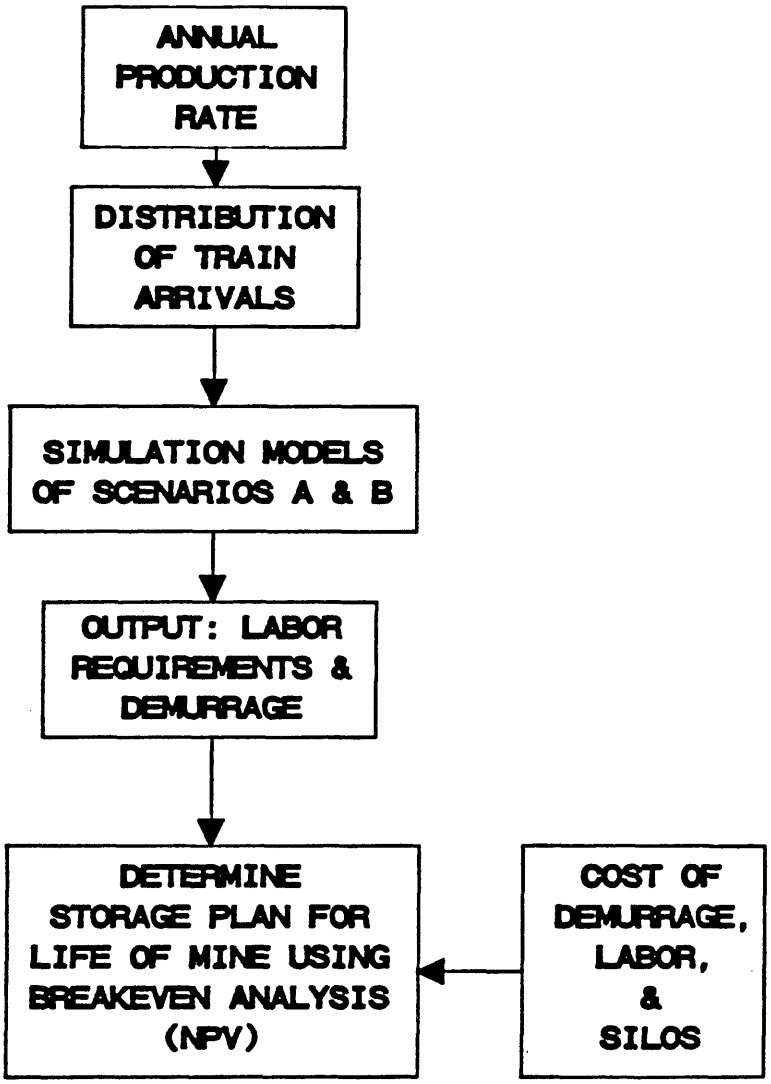

Figure 4.1

Flow Chart of Methodology

the capital cost of a silo, additional silos should be in place.

4.1 Scenarios A and B

Scenarios A and B, shown in Table 4.1, were constructed from historical data (Keystone Coal Industry Manuals, 1972-1983), and information obtained from people who are knowledgeable about mining activities in the Eastern Powder River Basin (Ausland, Glass, Jones, 1985). The annual production rates are expressed in thousand tons per year (TTPY). These 2 scenarios were chosen because they are representative of surface coal mines in the Eastern Powder River Basin, especially Scenario B. Scenario A was chosen because it demonstrates how the methodology for planning the construction of additional silos could be applied to a very large operation, even though the large operations tend to also have barns, or slots, for coal storage and loadout.

The plant capacities for these 2 scenarios were chosen by first calculating the total hours of planned operation per year, illustrated below.

255 working days per year x 20 hours per day x .8
= 4100, or approximately 4000 hours per year.

Table 4.1

Annual Production Rates and Average Daily Train Arrivals for Scenarios A and B

	Scenario A		Scenario B	
Year	Annual Production Rate (TTPY)	Avg. Train Arrivals Per Day	Annual Production Rate (TTPY)	Avg. Train Arrivals Per Day
1	1,800	.51	2,130	.60
2	4,680	1.32	2,890	.82
3	8,190	2.31	3,830	1.08
4	8,700	2.45	6,500	1.83
5	10,500	2.96	8,300	2.34
6	11,850	3.34	9,000	2.54
7	14,370	4.05	10,000	2.82
8	15,000	4.22	10,400	2.93
9	15,410	4.34	10,475	2.95
10	15,820	4.46	10,550	2.97
11	16,230	4.57	10,625	2.99
12	16,640	4.69	10,700	3.01
13	17,050	4.80	10,775	3.03
14	17,460	4.92	10,850	3.06
15	17,870	5.03	10,925	3.08
16	18,280	5.15	11,000	3.10
17	18,690	5.26	11,075	3.12
18	19,100	5.38	11,150	3.14
19	19,510	5.50	11,225	3.16
20	19,920	5.61	11,300	3.18
21	20,330	5.73	11,375	3.20
22	20,740	5.84	11,450	3.23
23	21,250	5.96	11,525	3.25
24	21,560	6.07	11,600	3.27
25	21,970	6.19	11,675	3.29
26	22,380	6.30	11,750	3.31
27	22,790	6.42	11,825	3.33
28	23,200	6.54	11,900	3.35
29	23,610	6.65	11,975	3.37
30	24,020	6.77	12,125	3.42

The 255 days per year was chosen because of the assumption that the plant will not be working on weekends. Twenty hours was chosen instead of 24 hours to account for shift changes, and the .8 is the percentage of the time that the plant is assumed to be availabile.

If the plant is operating 4000 hours per year, then to process 12,000,000 tons per year (tpy) requires that the plant capacity be equal to

$$(12{,}000{,}000 \text{ tpy})/(4000 \text{ hours per year})$$
$$= 3000 \text{ tph.}$$

Likewise, the plant capacity required to process 24,000,000 tons per year is

$$(24{,}000{,}000 \text{ tpy}) /(4000 \text{ hours per year})$$
$$= 6000 \text{ tph.}$$

For these 2 scenarios, notice that the annual growth rate in production is not constant and tends to increase rapidly in the first several years, rising sharply in some years and remaining constant in other years. Because data was available only for the first 8 years of production, these are the only years in which this "lumpiness" is

apparent. For years 9 through 30, the annual increase in production is constant. The annual production in Scenario A increases by 410,000 tons per year to reach the maximum output of 24,000,000 tons; and in Scenario B, the annual production increases by 75,000 tons per year to reach the maximum output of 12,000,000 tons. Such increases are, of course, unrealistic, for the production rate will tend to increase by millions of tons from one year to the next when a new contract is signed.

The acquisition of these new contracts cannot, however, be anticipated. Therefore, Scenarios A and B assume that the lumpiness is smoothed out for planning purposes. The effect of smoothing out the growth rate of annual production should not significantly alter the results. When labor and demurrage costs are calculated for years 9 through 30, the net present value analysis multiplies these costs by present worth factors ranging from .5002 to .0994 for years 9 to 30, respectively, for an interest rate of 8%. Therefore, the future projection of production rates, whether they increase by constant increments or highly variable increments, will not significantly affect the present worth cost, since these future costs are so heavily discounted. If a mine does have approximate dates of when future contracts will possibly be acquired and estimates of the tonnages, then they would

perhaps choose not to smooth out the future production rates so that the plan would be more realistic.

Besides production rates for Scenarios A and B, Table 4.1 also shows the average number of trains per day corresponding to each production rate. The next section demonstrates this conversion from annual production to average number of trains per day.

4.2 Converting from an Annual Production Rate to Average Number of Trains per Day

To convert from annual production rate to average number of trains per day, the annual production rate must first be established. Suppose that the production rate is 5,000,000 tons per year. Then the total number of trains which will arrive at the mine are

(5,000,000 tons per year)/(10,000 tons per train)
= 500 trains arrivals per year.

If it is assumed that trains can arrive at the mine 355 days out of the year, allowing 10 days for holidays, then the average number of train arrivals per day is

(500 train arrivals per year)/(355 days per year)

= 1.4 train arrivals per day.

4.3 Probability Distribution of the Number of Train Arrivals per Day

Determining the probability distribution of the number of train arrivals per day is necessary because the number of train arrivals per day at the mine will be modeled as a random variable. This would not be necessary if the simulation model approximated the number of train arrivals in a day by simulating the cycling of trains from the mine to the utility and back to the mine. If, however, mine management wants a predictive type of simulation model that anticipates future storage and loadout requirements, then information about future requirements per customer is not available. Mine management will, as a rule, not know precisely what the future contract obligations will be. Therefore, we would argue that it is more appropriate to model the number of train arrivals per day as a random variable. In order to determine the probability distribution, data which gave the number of train arrivals per day for 576 consecutive days at a mine in the Eastern Powder River Basin was made available for statistical analysis.

The average number of train arrivals per day was 4.12. Conducting a goodness-of-fit-test revealed that the data could be approximated by a Poisson distribution with a mean of 4.12.

In order to test the data for the goodness-of-fit to a Poisson distribution, the expected number of arrivals per day had to first be calculated. Since the train data had a daily mean of 4.12, the Poisson distribution with the same mean was established. The probability of y train arrivals per day is given by

$$p(y) = (L^y/y!)\ e^{-L},$$

where L = the mean, or 4.12.

The probability of 0,1,2, . . . ,8, 9 or more train arrivals per day was calculated and the results are given in column 2 of Table 4.2. Next, the expected number of train arrivals for each category was calculated by multiplying column 2 by 576, the total number of observations.

A goodness-of-fit test was conducted using "Minitab" (Ryan, et al., 1981). The results of this test are presented in Table 4.3. The Chi square test statistic was less than 21.666, the critical value for a confidence level

Table 4.2

Probabilities and Expected Number of Train Arrivals for the Poisson Distribution

y	p(y)	E(trains)
0	.016	9
1	.067	39
2	.138	80
3	.189	109
4	.195	112
5	.161	93
6	.110	63
7	.065	37
8	.033	19
9 or more	.026	15

of 99% (alpha = .01). Therefore, the null hypothesis, that the observed data follows a Poisson distribution, is accepted.

Since the actual data fits a Poisson distribution for L = 4.12, it will be assumed that for a mean number of train arrivals other than 4.12, the train arrivals also follow a Poisson distribution. Figure 4.2 shows the distribution of train arrivals per day for the available data.

In addition, statistical tests revealed no significant

Table 4.3

Output from Goodness-of-Fit Test

1	4	33	64	107	129	124	68	34	7	6
	6.5	36	72	108	120.5	108.5	65.5	35.5	13	10.5
2	9	39	80	109	112	93	63	37	19	15
	6.5	36	72	108	120.5	108.5	65.5	35.5	13	10.5

Total .96 +.25 +.89 +.01 +.60 +2.21 +.01 +.06 +2.77+1.93

Chi +.96 +.25 +.89 +.01 +.60 +2.21 +.01 +.06 +2.77+1.93

Square

=19.38

For alpha = .01, Chi Square = 21.66. Since 19.38 < 21.66, the null hypothesis, that the data fits a Poisson distribution, is accepted.

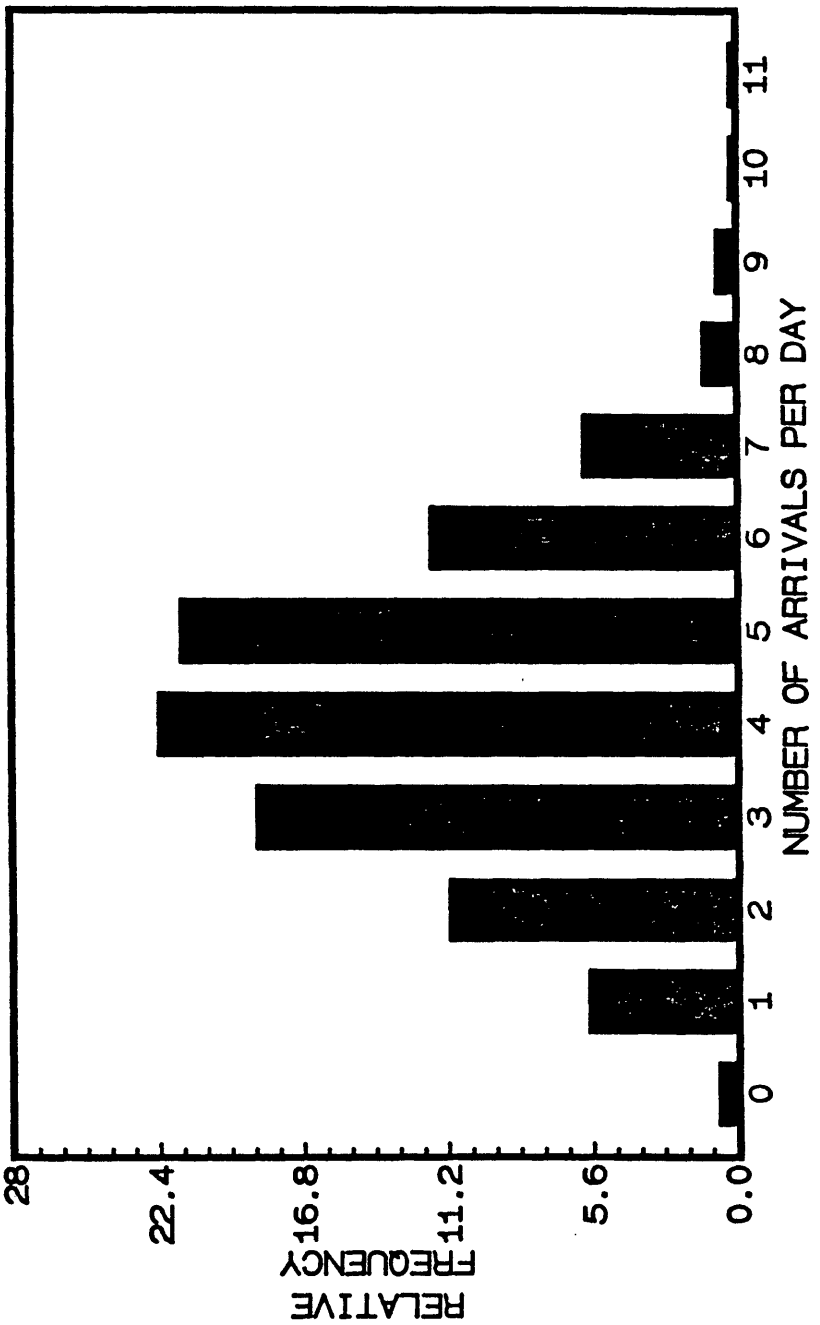

Figure 4.2

Distribution of Train Arrivals When the Mean Equals 4.12

differences between the number of train arrivals on different days of the week. This result is supported by statistical studies done by Exxon Coal (Mayo, 1984). Since there were not enough months of observations to develop reliable statistics on seasonality to either prove or disprove its existence, two experts on train arrivals in the Eastern Powder River Basin were contacted (McFarlend, Mayo, 1984). Both believed that the perception of seasonality in the Eastern Powder River Basin is incorrect. Furthermore, Exxon Coal (Mayo, 1984) did studies to detect seasonality of train arrivals in the Powder River Basin and, based on 36 months of data, detected no seasonality. Therefore, the simulation runs in this analysis assume no seasonality in the number of train arrivals and no differences between the number of weekend and weekday train arrivals.

The major shortcoming with the available train arrival data is that the data does not specify the time of day of the arrivals or indicate the time between arrivals. The simulation, however, is based on time and the hours between train arrivals, information which is not available in the public domain. Nonetheless, this information can be inferred from the Poisson distribution. In the simulation model, the number of train arrivals in a day is a random variable which has a Poisson distribution. To convert from

number of arrivals to time between arrivals, 24 is divided by the number of train arrivals per day (unless this number is equal to 0).

For example, if there are 3 train arrivals per day, then the time between arrivals is approximately equal to 8 hours. In the simulation model, a FORTRAN subroutine divides 24 by 3 and multiplies this by 2 factors. The first factor is less than 1 and, when multiplied by (24/3), is called ALO. The second factor is greater than or equal to 1 and, when multiplied by (24/3), is called AHI. The time between train arrivals is defined to be uniformly distributed between ALO and AHI. If the number of train arrivals is equal to 0, then the time between train arrivals is uniformly distributed between a lower bound and an upper bound which vary depending on the mean of the Poisson distribution. The 2 factors used to calculate ALO and AHI also vary depending on the mean of the Poisson distribution.

All 4 of these parameters were chosen by trail and error. The procedure used to determine these 4 parameters was to run the simulation models until the correct number of total train arrivals per year was generated (to yield the desired tonnage). Sometimes the number of simulation runs made was substantial before this correct result was obtained. When the simulation run used in this trial and

error procedure finally did yield the correct total number of train arrivals, then the combination of parameters generating this information was chosen.

These parameters were used in additional simulation runs for the same mean number of train arrivals per day and the same number of silos. These parameters are not unique, and they were chosen because they generated the correct total number of train arrivals per year, yielding the desired tonnage. Table 4.4 shows the values of these 4 parameters chosen for each of the different types of simulation runs. (The differences between the types of simulation runs are plant capacity, average number of train arrivals, and number of silos.)

Shown in Table 4.5 are other parameter values which were tried but did not yield the correct number of train arrivals per year. For example, when the trial and error procedure was performed for a mean number of daily train arrivals equal to 4.27, the factors chosen for ALO and AHI were .25 and 1.1. The lower and upper bounds chosen for the uniform distribution (when the number of train arrivals was equal to zero) were 24 and 28 hours. These parameters resulted in a total of 1659 total train arrivals for the year, much more than the required 1516 trains needed to meet contract tonnage requirements.

Table 4.4

Parameters Which Yielded the Correct Number of Annual Train Arrivals

L	No. of Silos	Scenario	Uniform Distribution Lower Bound	Uniform Distribution Upper Bound	Factor for ALO	Factor for AHI
0.51	1	A	30	96	.90	1.1
1.32	1	A	24	30	.70	1.1
2.57	1	A	24	28	.25	1.1
3.34	1	A	24	28	.25	1.1
4.27	1	A	24	28	.25	1.2
4.80	1	A	24	28	.25	1.2
5.15	1	A	24	28	.25	1.2
5.44	2	A	24	28	.30	1.25
5.96	2	A	24	28	.35	1.25
6.60	3	A	24	28	.35	1.25
0.83	1	B	30	54	.90	1.1
1.83	1	B	24	30	.30	1.1
2.56	1	B	24	28	.25	1.1
3.00	1	B	24	28	.25	1.1
3.25	1	B	24	28	.25	1.1

Table 4.5

Parameters Which Yielded the Incorrect Number of Annual Train Arrivals

L	No. of Silos	Scenario	Uniform Distribution Lower Bound	Uniform Distribution Upper Bound	Factor for ALO	Factor for AHI
0.51	1	A	24	72	.90	1.1
0.51	1	A	30	72	.90	1.1
0.51	1	A	30	72	.80	1.1
0.51	1	A	30	84	.80	1.1
0.51	1	A	30	84	.80	1.0
0.51	1	A	30	84	.90	1.2
0.51	1	A	30	84	.95	1.25
0.51	1	A	30	96	.95	1.25
1.32	1	A	30	96	.90	1.1
1.32	1	A	30	72	.90	1.1
1.32	1	A	24	72	.85	1.05
1.32	1	A	24	30	.50	1.1
1.32	1	A	24	30	.60	1.1
1.32	1	A	24	36	.90	1.1
1.32	1	A	24	36	.90	1.0
1.32	1	A	24	30	.50	1.1
4.27	1	A	24	28	.25	1.1
0.83	1	B	30	60	.90	1.1
1.83	1	B	24	30	.40	1.1
1.83	1	B	24	30	.35	1.1
1.83	1	B	24	28	.35	1.1
1.83	1	B	30	54	.90	1.1
2.56	1	B	24	30	.35	1.1
2.56	1	B	24	30	.30	1.1
2.56	1	B	24	28	.30	1.1
3.00	1	B	24	30	.30	1.1
3.00	1	B	24	28	.20	1.1

4.4 Simulation Models

The types of simulation models chosen to be run are based on the production rates and average daily number of train arrivals in Scenarios A and B. (Refer to Table 4.1.) The runs span a period of 1 year. They will not, however, be run for each of the 30 years for Scenarios A and B. Sixty different types of simulation runs would be much to extensive. (Each type of run requires at least 5 separate simulation runs, so this task would actually require at least 300 runs.) Therefore, the different simulations were carefully chosen, based on the average number of daily train arrivals. For example, in Scenario B the first 3 years of production are within 1,000,000 tons of year 2, and the number of daily train arrivals range from .6 to 1.08, averaging .83. Because the annual production and number of train arrivals in these 3 years were fairly close, a simulation model was run with an average number of daily train arrivals equal to .83, and the results applied to all 3 years. Year 4 requires 1.83 average train arrivals per day, significantly different from the average number of train arrivals in the previous 3 years and in the fifth year. Therefore, simulation runs were made for year 4, with the average daily train arrivals equal to 1.83.

The general rule-of-thumb for deciding which year to simulate is based on the average daily number of train arrivals. When this number is .50 greater than the previous year(s), then simulation runs are made. This rule-of-thumb fit Scenario B until year 16, when the average number of daily train arrivals for years 16 through 30 was equal to 3.25, only 0.25 trains greater than the average number of train arrivals for years 8 through 15. Nonetheless, it is imperative to simulate the later years in the mine's life because the objective of this study is to develop a storage plan for the life of the mine.

An exception to this rule also occurred in Scenario A. Table 4.6 shows the different types of simulation runs made for Scenarios A and B. Note that a simulation run was made for year 16 for 5.15 average train arrivals per day, which is not .50 greater than the previous runs made or .50 less than the following runs made. A simulation run was made for year 16 because the breakeven analysis showed that the discounted costs of labor and demurrage in year 15 were nearly equal, but slightly less than, the cost of a silo. Instead of extrapolating the costs of years 11 through 15 to include year 16, a simulation run was made for the sixteenth year.

The identical situation occured after simulation runs

Table 4.6

Simulation Runs Made for Scenarios A and B

Simulation Runs made for Scenario A
(Plant capacity = 6000 tph)

Average Number of Train Arrivals	Year(s) Spanned	Number of Silos
0.51	1	1
1.32	2	1
2.57	3-5	1
3.34	6	1
4.27	7-10	1
4.80	11-15	1
5.15	16	1
5.44	17-20	2
5.96	21-26	2
6.60	27-30	3

Simulation Runs made for Scenario B
(Plant Capacity = 3000 tph)

Average Number of Train Arrivals	Year(s) Spanned	Number of Silos
0.83	1-3	1
1.83	4	1
2.56	5-7	1
3.00	8-15	1
3.25	16-30	1

were made for years 21 through 25. The discounted costs of labor and demurrage in year 25 were slightly less than the cost of a silo. In this case, instead of doing a simulation run for year 26, it was assumed that the discounted costs for year 25 would be an appropriate estimate for the discounted costs in year 26, especially since the uncertainty of predicting 26 years into the future is so high.

The different types of simulation runs made for Scenario A and B are distinguished by 3 different parameters: average number of daily train arrivals, plant capacity, and number of silos. At least 5 runs are made for each type of simulation and the results averaged together.

The simulation models will be based on the Activity Chart in Figure 4.3 and the assumptions listed in Table 4.7. In the activity chart, the first event is the arrival of a train at the mine. After the train arrives the model determines whether it's a weekend or a weekday and, if it's a weekend, collects weekend labor and demurrage information. The model defines the start of the first weekend to occur 120 hours into the simulation. The next 24 hours are defined as Saturday, and the next 24, as Sunday. Again, 120 hours later, Saturday begins.

The train proceeds to the loadout point, and, if there

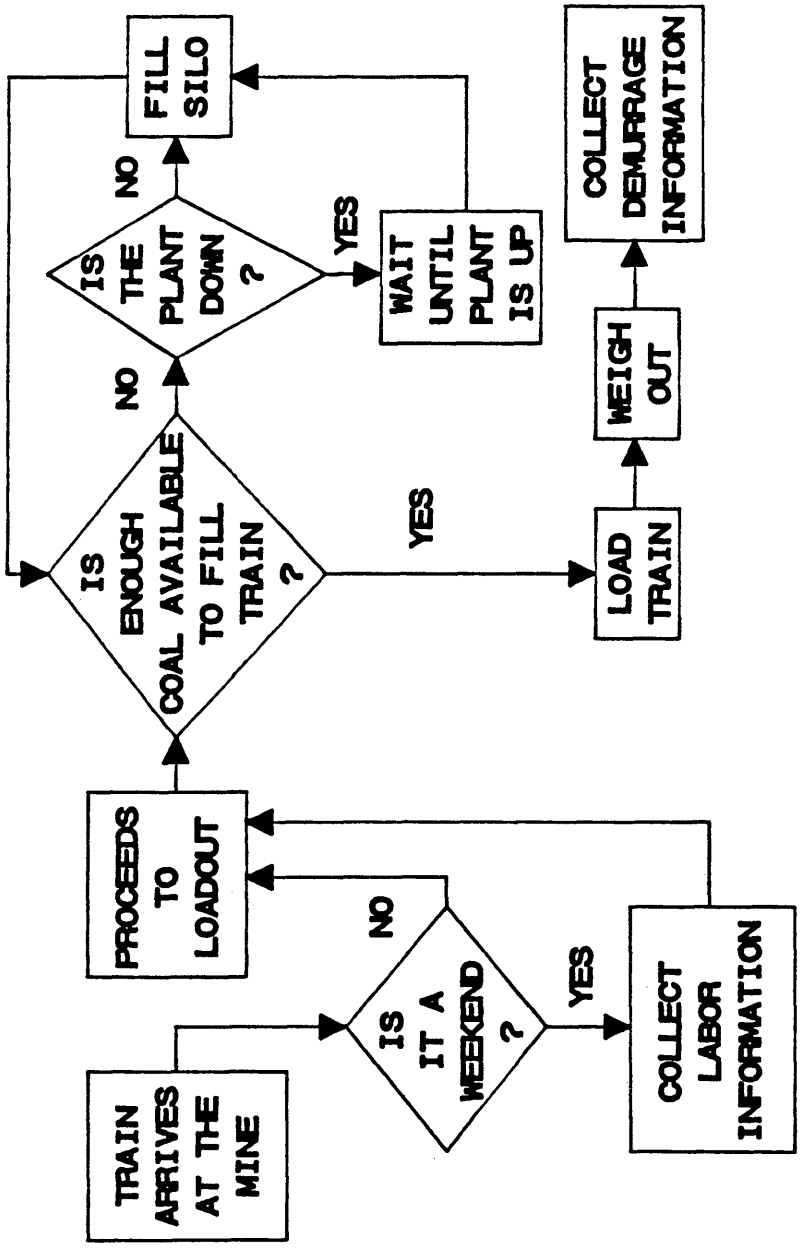

Figure 4.3

Mine Activity Flow Chart

Table 4.7

Assumptions of the Simulation Model

1. Silo capacity (live) = 10,500 tons.
2. Train capacity = 10,000 tons.
3. Plant downtime = 20%.
   The frequency between failures is uniformly distributed between 5 and 55 hours.
   The duration of each failure is uniformly distributed between 2 and 8 hours.
4. Total potential annual operating hours = 8500 hours.
   Even though the plant capacity is calculated by assuming 4000 hours of operation, it could potentially be operating more than that if trains arrive anywhere within the 8520 hours possible throughout the year. Therefore, the plant could go down anywhere during this 8520 hour period, including planned downtime for preventive maintenance. Since the plant could conceivably be working during this larger time period, downtime is calculated using this larger number of 8500 (8520 is rounded off to 8500.).
5. The silo is filled before a train is loaded. Simultaneous filling of silo and train does not occur.
6. The number of daily train arrivals can be described by the Poisson ditsribution.
7. There is one rail loop.

is enough coal to fill the train, the train is loaded and weighs out. If, on the other hand, there is not enough coal to fill the train, then the silo(s) must be filled first. Before the silo can be filled, the plant must be up, so the model determines whether the plant is up or not. If the plant is up, the train is loaded and weighs out. If the plant is down, the train must wait until the plant is operational so that the silos can be filled. The duration of this delay depends on the frequency and duration of downtime. Downtime is assumed to be 20% of total time. Since data for the time between failures and the duration of the failures is proprietary information, the model was constructed to generate a total of 20% of 8500 hours down, or 1700 hours. It assumed that the plant is unable to fill the silos approximately every 25 hours and the duration of the failure is approximately 5 hours. (8500 hours/25 hours = 340 occurences. 340 x 5 hours = 1700 hours.)

After a train is loaded and weighs out, the simulation model calculates the total time each train was in the mine, from which demurrrage information is extracted. The output from the simulation models and it use is discussed in section 4.6. Program listings for the different cases are listed in Appendixes 2 and 3.

4.5 Output from the Simulation Models

The simulation models are constructed to collect several different types of data and information. Some of this information is presented in the form of a histogram and other information is presented in a table which gives statistical information. The statistical information which is given for a particular item is the mean value, the standard deviation, the coefficient of variation, minimum and maximum values, and the number of observations. Table 4.8 shows all the items and corresponding statistics which are collected by the simulation model.

Not all of this information, however, is used in performing the cost analysis to determine when additional storage capacity should be built. Some of this information is only used as a check to ensure that the simulation model is performing as intended. In particular, information about the first two items, time between arrivals and number of arrivals, is used for checking to determine whether the simulation yields appropriate results for the mean number of train arrivals which was used as an input into the simulation model. The time between arrivals is presented in the form of a histogram, shown in Figure 4.4. The upper cell limit in Figure 4.4 represents the hours between train

Table 4.8

Statistics Collected by the Simulation Model

Item	Mean Value	Standard Deviation	Coeff. of Variation	Minimum Value	Maximum Value	No. of Observations
1. Time B Arrivals	4.446	3.638	.8182	.5267	27.88	1907
2. Number Arrivals	5.404	2.290	.4239	0.000	16.00	1907
3. Demurrage All	3.331	.2863	8.595	0.000	4.294	1906
4. Weekend Arrival	264.4	156.1	.5905	0.000	528.0	1906
5. Time into Wkend	6.547	12.91	1.972	0.000	47.89	1906
6. Wkend Demurrage	.0049	.1110	22.58	0.000	3.543	1906
7. Time Fillin Silo	3.157	2.640	.8365	1.188	18.64	947
8. TT Fill Silo Sat	251.4	125.8	.5003	0.000	445.0	947
9. TT Fill Silo Sun	236.1	135.3	.5733	0.000	440.9	947
10. Time Fillin Tran	.9888	.5736	.5800	.7813	7.031	1906
11. TT Fill Tran Sat	134.2	75.50	.5627	0.000	252.9	1906
12. TT Fill Tran Sun	130.0	74.36	.5718	0.000	247.1	1906

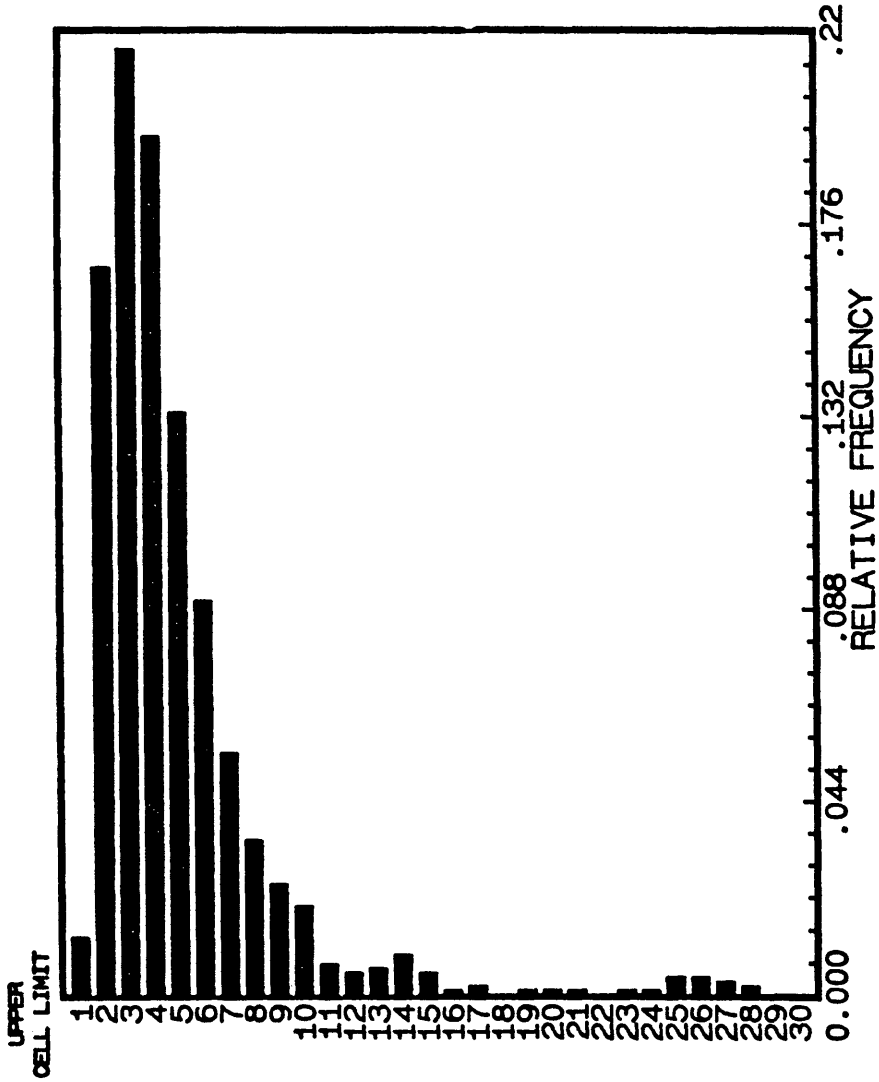

Figure 4.4

Time Between Train Arrivals (in hours)

arrivals. The number of train arrivals corresponding to each upper cell limit is expressed as a percentage of the total number of annual train arrivals, and appears as relative frequency along the horizontal axis.

Other items such as demurrage are used in the cost analysis, but must first be manipulated before the data can be used in the analysis. For example, the third item in Table 4.8 "demurrage all" calculates train waiting time for weekdays and weekends, whereas the sixth item, "wkend demurrage" calculates train waiting times only on weekends. Demurrage is a misleading nomenclature in this case because the information given is for the train waiting and loading time from the time the train enters the mine at the scale until the time the train is completely loaded. Since demurrage allows a 4 hour grace period, if the total time is greater than four, then the 4 hours of grace is subtracted from this total time, and the remainder is demurrage. This type of manipulation cannot be done if the data is presented in a statistical format as in Table 4.8. Therefore, "demurrage all" and "wkend demurrage" are more useful if they are presented in the form of a histogram which calculates how many trains used specific amounts of time to load. An example of the histogram for "demurrage all" is shown in Figure 4.5. (The histogram for "wkend demurrage" is

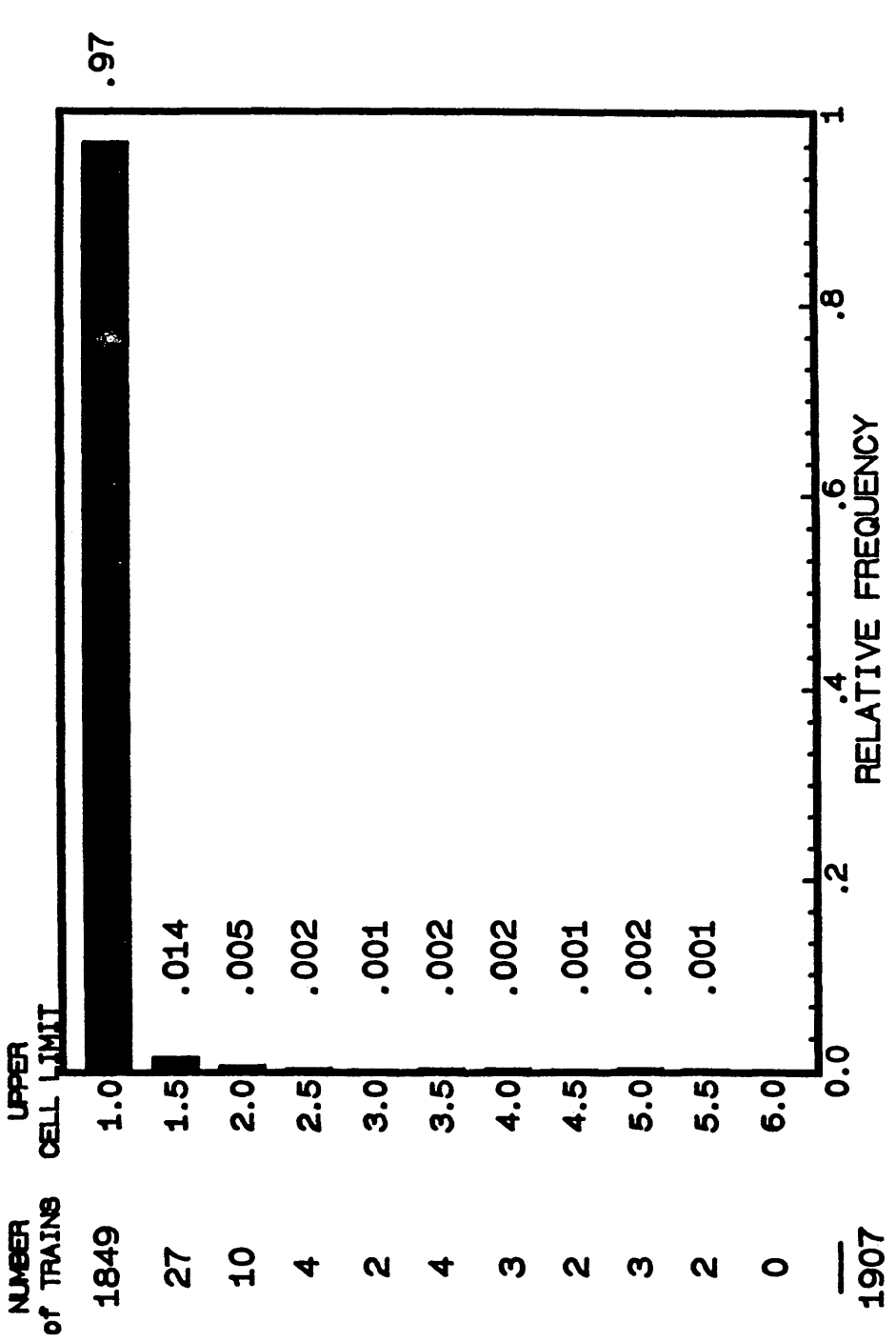

Figure 4.5

Total Time for Trains to Wait for an Available Silo and to Load

identical in format and similar in content. Therefore, it is not shown.) Since demurrage allows a 4-hour grace period, there is no special interest in upper cell limits less than 4. Therefore, for upper cell limits in the histogram which are greater than 4, the difference between 4 and this upper cell limit is the number of hours of demurrage incurred by the number of trains listed in the far left hand column under "number of trains". For example, in Figure 4.5, 2 trains used 4.5 hours to wait for an availble silo and load, 3 trains used 5 hours to wait for an available silo and to load, and 2 train used 5.5 hours. Since demurrage allows 4 hours of grace, the 2 trains incurred .5 hours of demurrage each, for a total of 1 hour. The 3 trains incurred 1 hour of demurrage each, for a total of 3 hours, and the 2 trains incurred 1.5 hours of demurrage each, for total demurrage of 3 hours. Thus, the grand total for demurrage is 7 hours.

Discussions with people in the Eastern Powder River Basin indicate that several different definitions of demurrage exist (see Dewey; Ausland; and Rowe). The total time against which demurrage is measured has been defined as spanning the length of time from 1) the entrance at the scale until the train starts loading, 2) brake check to brake check, and 3) the time the first car crosses the scale

on the way in to the time the last car crosses the scale on the way out. The first definition would result in the minimum amount of demurrage, the third would result in the maximum amount of demurrage. This study defines the span of time against which demurrage is measured as starting when the train enters the mine at the scale (before the first brake check), and ending when the train is loaded (before the second brake check). These endpoints were chosen because they were easy to identify and measure in the simulations, and they result in demurrage which lies somewhere between the 2 extreme definitions (numbers 1 and 3). The simulation model can be adjusted to measure demurrage in other ways if a user desires to do so. These adjustments are discussed in Chapter 5.

Another item for which statistics are collected is "weekend arrival" (line 4, Table 4.8). The only values which are used are in the last 2 columns, "maximum value" and "number of observations." The number in the column under "maximum value" is the total number of trains which arrived on the weekends. The last column shows the total of train arrivals in the year.

The fifth item in Table 4.8, "time into weekend," is useful only as a histogram which shows the percentage of the total annual number of trains arriving at different points

in time throughout the weekend. This histogram, shown in Figure 4.6, is used to justify using an average hourly wage rate which gives equal weight to daytime pay, the P.M. shift with a 25-cent differential, and to the A.M. shift with a 35-cent differential. Details of how this information is used are presented in section 4.6, Calculation of Costs.

The remaining 6 items in Table 4.8 for which the simulation model collects information are all related to labor. Items 7 and 10, "time filling silo" and "time filling train" show statistical information about the duration and variability of the length of time required to fill the silos and trains, based on the inputs into the model. The model specifies a train filling rate which is uniformly distributed between 9990 tph and 10,010 tph. The silo fill rate is between 2700 tph and 3300 tph for a plant rated at 3000 tph capacity, and between 5400 and 6600 tph for a plant rated at 6000 tph.

Items 8 and 9 show the total time used to fill the silo(s) on Saturday and Sunday for the entire year. This time is shown in column 6, under "maximum value." Because the simulation model keeps track of the labor hours by continually accumulating and adding the hours to fill the silo, the rest of the statistical information for this item is not used except for the number of observations. When the

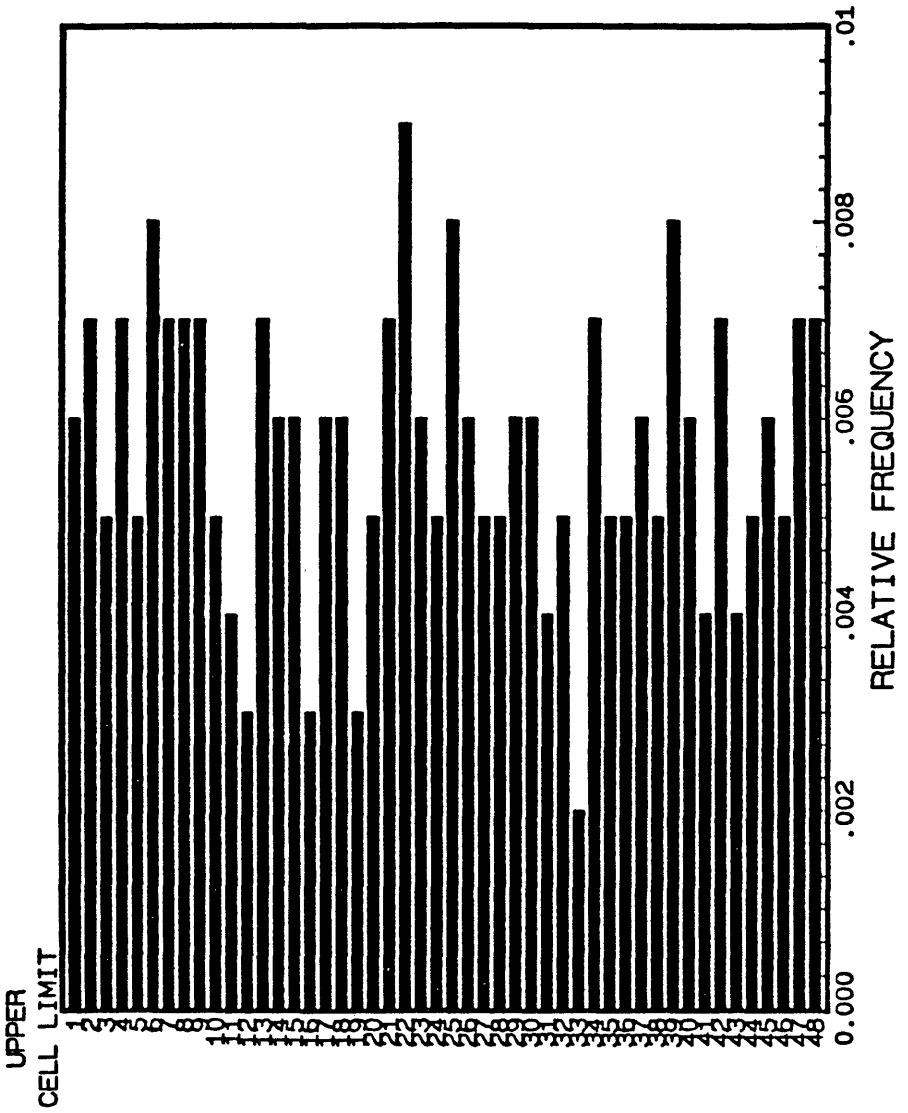

Figure 4.6

Total Number of Trains Arriving at Different Times Throughout the Weekend

simulation model is run with 2 silos, the number of observations for items 7, 8, and 9 is about half the number of observations for the other items. This difference occurs because each silo in the 2-silo case handles about the same number of trains, cutting the number of observations per silo in half.

Items 11 and 12 in Table 4.8 show the total time to fill the trains on Saturday and Sunday for the entire year. Only the last 2 columns, the maximum value and number of observations, contain pertinent information. The maximum value is the total annual labor hours spent on Saturday and Sunday to fill trains.

Five pieces of information from the simulation model are used in performing the break-even analysis. The rest of the information from the simulation model is used for other types of analysis (such as in calculating an average wage rate for all 3 shifts), or used to verify that the model is working correctly and generating appropriate results. The 5 types of information which are used in the break-even analysis are: the histogram for "demurrage all" (Figure 4.5); the total labor hours to fill the train on Saturday; the total labor hours to fill the train on Sunday; the total labor hours to fill the silo on Saturday; and the total labor hours to fill the silo on Sunday. Before this

labor information can be used in the breakeven analysis, the labor costs must be derived. In addition, demurrage costs and the capital cost of a silo must also be calculated. The next section, 4.6, discusses the derivation of these costs.

4.6 Derivation of Costs

In order to calculate the hourly incremental labor costs for filling silos and filling trains, the labor rates for each position associated with these 2 tasks was first obtained (Rowe, 1985). From this data, the total hourly cost of regular time pay was established for 2 different crews--one crew to fill the silo(s) and another crew to fill the train(s). The crew required to fill a silo(s) consists of the people working in the pit who keep the plant supplied with coal. This crew will be larger for a larger plant. In this case, the crew required to keep a 3000-tph plant supplied with coal consists of 11 people (including 1 supervisor), corresponding to Scenario B. Table 4.9 shows how the total hourly cost for the 2 crews is calculated assuming a 3000-tph plant. After calculating the costs for each crew, the incremental wage rate is calculated, taking into account the shift differentials.

Since the Saturday wage is 1.5 times the regular rate of

Table 4.9

Calculation of Regular Hourly Labor Costs for Crews Filling Silos and Trains

Description	Number of Operators	Hourly Wage Rate	Total Hourly Cost
Crew to fill silo*			
Shovel operator	1	$18.91	$18.91
Truck driver	3	17.52	52.56
General laborer	2	16.78	33.56
Mechanic	2	18.12	36.24
Electrician	2	18.12	36.24
Supervisor**	1	21.25	21.25
		Total cost	$198.76
Crew to fill train			
Plant personnel	2	$16.78	$33.56
Train loading personnel	2	18.91	37.82
Supervisor**	1	21.25	21.25
		Total cost	$92.63

*Assuming the plant capacity is 3000 tph

**The supervisor's pay rate is $170 per day. The hourly rate of $21.25 was calculated by dividing $170 per day by 8 hours.

pay, the incremental cost is 50% of the regular rate of pay. Likewise, the incremental cost on Sunday is 100% of the regular rate of pay, since Sunday work pays double time. This incremental cost must also account for shift differentials by multiplying the number of people on each crew (except the supervisor) times the shift differential of 25 cents for the P.M. shift or 35 cents for the A.M. shift, and then calculating the incremental cost. For example, the incremental cost for the silo crew on the Saturday P.M. shift is calculated as follows:

(10 operators) x ($0.25 differential) = $2.50

Total hourly cost for P.M. shift = $198.76 + 2.50 = $201.26

Incremental hourly cost = .50 x $201.26

= $100.63

Incremental costs for Sunday are calculated the same way except the incremental hourly cost is determined by multiplying the total hourly cost on a shift by 1.0 instead of .50, shown in the following equation which calculates the incremental cost for the A.M. shift:

[(10 operators x $.35/hour) + ($198.76)] x 1.0 = $202.26

Table 4.10 shows the incremental hourly costs for each crew on Saturdays and Sundays for all 3 shifts as well as the average hourly cost for each crew.

Since the simulation model does not differentiate between shifts, the incremental hourly costs for each crew on Saturday and on Sunday were averaged together, the hourly cost of each shift being given equal weight, because output from the simulation model indicated that about the same percentage of trains arrived during each shift throughout the weekend. The histogram "time into weekend" given in Figure 4.6 contains this information, showing how many trains arrived each hour throughout the weekend.

For a plant capacity of 6000 tph, corresponding to Scenario A, the size of the crew to fill a silo should be doubled, except for the supervisor who can tend to both crews. The crew size is doubled because the capacity of the shovel is 3000 tph, half that of the plant. The size of the crew requried to fill the train, however, will remain the same. Table 4.11 shows the total hourly cost of the crew required to fill the 6000 tph plant, calculates incremental hourly costs for the shifts on Saturday and Sunday, and determines the average hourly labor cost on Saturday and Sunday.

To summarize, this section developed the method for

Table 4.10

Incremental Hourly Costs for Weekend Crews
for a 3000-tph Plant Capacity

Shift	Incremental Hourly Costs	
	Crew to Fill Silo	Crew to Fill Train
Saturday days	$ 99.38	$46.32
Saturday P.M.	100.63	46.82
Saturday A.M.	101.13	47.02
Average cost	$100.38	$46.72
Sunday days	198.76	92.63
Sunday P.M.	201.26	93.63
Sunday A.M.	202.26	94.03
Average cost	$200.76	$93.43

Table 4.11

Calculation of Costs for a Crew to Fill Silos
for a 6000-tph Plant Capacity

Description	Number of Operators	Hourly Wage Rate	Total Hourly Cost
Crew to fill silo			
Shovel operator	2	$18.91	$ 37.82
Truck driver	6	17.52	105.12
General laborer	4	16.78	67.12
Mechanic	4	18.12	72.48
Electrician	4	18.12	72.48
Supervisor	1	21.25	21.25
		Total cost	$376.27

Shift	Incremental Hourly Cost
Saturday days	[376.27] x .50 = 188.14
Saturday P.M.	[(20 x .25) + (376.27)] x .50 = 190.64
Saturday A.M.	[(20 X .35) + (376.27)] X .50 = 191.64

Average cost = $190.14

Sunday days	[376.27] x 1.0 = 376.27
Sunday P.M.	[(20 x .25) + (376.27)] x 1.0 = 381.27
Sunday A.M.	[(20 x .35) + (376.27)] x 1.0 = 383.27

Average cost = $380.27

calculating incremental labor costs required to fill trains and silos on weekends. If a mine staffs its crews differently, it is a simple matter to adjust the cost data to account for these differences. In this particular study, the hourly incremental labor costs which will be used in the break-even analysis for each scenario are summarized in Table 4.12.

Table 4.12

Incremental Hourly Cost for the Two Different Types of Crews and Plant Capacities

Type of Crew	Plant Capacity(tph)	Incremental Labor Cost Saturday	Sunday
Fill trains	3000 or 6000	$46.72	$93.43
Fill silo	3000	$100.38	$200.76
Fill silo	6000	$190.14	$380.27

The cost of demurrage ranges from $250 to $400 per hour (McFarlend, 1985). The conservative estimate of $250 per hour will be used. In this study, the total annual cost of demurrage will be calculated by multiplying the total hours of demurrage by $250 per hour, a simple, straightforward calculation.

The capital cost of a silo, including design, engineering, and construction, was obtained from McNally-Pittsburgh (Cahill, 1985). The cost estimate for a 10,500 ton, over-the-track silo is approximately $2 million. The cost of this silo will be compared with the costs of labor and demurrage in a break-even analysis to determine when to build additional silos. The next section discusses this break-even analysis.

4.7 Break-even Analysis

The break-even analysis is constructed by first determining the total annual cost of labor and demurrage for each year of operation. These costs are then discounted at an interest rate of 8%. When the cumulative discounted cost is equal to the cost of a silo, the silo should be built.

Table 4.13 shows how the total annual labor costs are calculated for Scenario A. The simulation runs for year 1 show that the silo crew worked 59 hours on Saturday and 52 on Sunday, and the the train crew worked 24 and 21 hours on Saturday and Sunday, respectively. Multiplying each of these labor hours by the hourly labor rates derived in section 4.6 (See Table 4.12.) results in the total annual labor cost for each crew. Summing these costs horizontally

Table 4.13

Total Annual Labor Costs for Scenario A

	Silo Labor				Train Labor				Total
	Saturday		Sunday		Saturday		Sunday		Labor
Year	Hrs	x $190.14	Hrs	x $380.27	Hrs	x $46.72	Hrs	x $93.43	Cost
1	59	11,218	52	19,774	24	1,121	21	1,962	34,075
2	137	26,049	140	53,238	58	2,710	60	5,606	87,603
3	264	50,197	258	98,110	148	6,915	150	14,015	169,237
4	264	50,197	258	98,110	148	6,915	150	14,015	169,237
5	264	50,197	258	98,110	148	6,915	150	14,015	169,237
6	361	68,641	320	121,687	237	11,073	206	19,247	220,648
7	412	78,338	422	160,414	300	14,016	319	29,804	282,572
8	412	78,338	422	160,414	300	14,016	319	29,804	282,572
9	412	78,338	422	160,414	300	14,016	319	29,804	282,572
10	412	78,338	422	160,414	300	14,016	319	29,804	282,572
11	466	88,605	459	174,544	366	17,100	362	33,822	314,071
12	466	88,605	459	174,544	366	17,100	362	33,822	314,071
13	466	88,605	459	174,544	366	17,100	362	33,822	314,071
14	466	88,605	459	174,544	366	17,100	362	33,822	314,071
15	466	88,605	459	174,544	366	17,100	362	33,822	314,071
16	560	106,478	554	210,670	518	24,201	511	47,743	389,092
17	433	82,331	433	164,657	272	12,708	272	25,413	285,109
18	433	82,331	433	164,657	272	12,708	272	25,413	285,109
19	433	82,331	433	164,657	272	12,708	272	25,413	285,109
20	433	82,331	433	164,657	272	12,708	272	25,413	285,109
21	455	86,514	462	175,658	291	13,596	294	27,468	303.236
22	455	86,514	462	175,658	291	13,596	294	27,468	303,236
23	455	86,514	462	175,658	291	13,596	294	27,468	303,236
24	455	86,514	462	175,658	291	13,596	294	27,468	303,236
25	455	86.514	462	175,658	291	13,596	294	27,468	303,236
26	455	86,514	462	175,658	291	13,596	294	27,468	303,236
27	476	90,507	506	192,417	310	14,483	289	27,001	324,408
28	476	90,507	506	192,417	310	14,483	289	27,001	324,408
29	476	90,507	506	192,417	310	14,483	289	27,001	324,408
30	476	90,507	506	192,417	310	14,483	289	27,001	324,408

yields the total annual labor cost. The demurrage cost, however, must be included. The demurrage hours are first calculated by using the technique described in section 4.5. These demurrage hours are then multiplied by $250 to yield the total annual demurrage cost. Table 4.14 shows this demurrage calculation in columns (1) and (2). The annual demurrage cost in column (2) is added to the total annual labor cost from Table 4.13 to yield the grand total in column (3) of Table 4.14. Column (4) in Table 4.14 cumulates these grand totals, without discounting the costs. This technique represents the "pay back method" which is commonly used by coal industry analysts. According to the pay back method, the years in which silos should be built are years 10, 16, and 23, when the labor and demurrage costs are approximately equal to the cost of an additional silo, or $2 million.

The use of a discount rate requires slightly more complex calculations, shown in columns (5), (6), and (7) of Table 4.14. Column (3) is multipled by the present worth factor in column (5) to obtain the present-worth total cost, shown in column (6). Column (7) cumulates the costs in column (6) to determine when a silo should be built. The silo should be built when these cumulative costs sum to $2 million. The first should be built in year 16 and the

Table 4.14

Break-even Analysis and Storage Plan for Scenario A

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Demurrage		Grand	Cumulative		PW Value	Cumulative
Year	Hrs	x $250	Total	Value, i=0%	$(P/F_{8,n})$	(3) x (5)	PW value
1	0	0	34,075	34,075	.9259	31,550	31,550
2	0	0	87,603	121,678	.8573	75,102	106,652
3	3.4	850	170,087	291,765	.7938	135,015	241,667
4	3.4	850	170,087	461,852	.7350	125,014	366,681
5	3.4	850	170,087	631,939	.6806	115,761	482,442
6	13.4	3,350	223,988	855,927	.6302	141,157	623,599
7	33.2	8,300	290,872	1,146,799	.5835	169,724	793,323
8	33.2	8,300	290,872	1,437,671	.5403	157,158	950,481
9	33.2	8,300	290,872	1,728,543	.5002	145,494	1,095,975
10	33.2	8,300	290,872	2,019,415	.4632	134,732	1,230,707
11	59.1	14,775	328,846	2,348,261	.4289	141,042	1,371,749
12	59.1	14,775	328,846	2,677,107	.3971	130,585	1,502,334
13	59.1	14,775	328,846	3,005,953	.3677	120,917	1,623,251
14	59.1	14,775	328,846	3,334,799	.3405	111,972	1,735,223
15	59.1	14,775	328,846	3,663,645	.3152	103,652	1,838,875
16	117.7	29,425	418,517	4,082,162	.2919	122,165	1,961,040
17	6.0	1,500	286,609	4,368,771	.9259	265,371	265,371
18	6.0	1,500	286,609	4,655,380	.8573	245,710	511,081
19	6.0	1,500	286,609	4,941,989	.7938	227,510	738,591
20	6.0	1,500	286,609	5,228,598	.7350	210,658	949,249
21	6.0	1,500	304,736	5,533,334	.6806	207,403	1,156,652
22	6.0	1,500	304,736	5,838,070	.6302	192,045	1,348,697
23	6.0	1,500	304,736	6,142,806	.5835	177,813	1,526,510
24	6.0	1,500	304,736	6,447,542	.5403	164,649	1,691,159
25	6.0	1,500	304,736	6,752,278	.5002	152,429	1,843,588
26	6.0	1,500	304,736	7,057,014	.4632	141,154	1,984,742
27	0.7	175	324,583	7,381,597	.9259	300,531	300,531
28	0.7	175	324,583	7,706,180	.8573	278,265	578,796
29	0.7	175	324,583	8,030,763	.7938	257,654	836,450
30	0.7	175	324,583	8,355,346	.7350	238,569	1,075,019

second in year 26. Notice that in year 17, the present worth factor is the same as year 1. The rationale for using a year 1 factor instead of year 17 is that if a silo is built in year 16, then we are again at time 0, and the method for calculating costs is repeated, using 2 silos as a base case instead of 1.

The break-even analysis for Scenario B was conducted in the same way as the analysis for Scenario A, except that the labor rates for the silo labor are less since Scenario B uses only 1 crew and Scenario A, 2 crews. Table 4.15 shows the calculation of total labor costs for Scenario B and Table 4.16 develops the break-even analysis and the pay back method for Scenario B. The payback method shows that the silos should be built in years 12, 21, and 29. The net present value analysis recommends that an additional silo never be built. The purpose for using both the pay back method and the more correct and justifiable method based on net present value techniques, is that the time in which a silo should be built can be bounded. Of course, all mines will have different characteristics and objectives which will determine when additional silos should be built. Based on this analysis, the first silo for Scenario A should be built between years 10 and 16, the second between years 16 and 26, and the third, no sooner than year 23. For Scenario

Table 4.15

Total Annual Labor Costs for Scenario B

	Silo Labor				Train Labor				Total
	Saturday		Sunday		Saturday		Sunday		Labor
Year	Hrs	x $100.38	Hrs	x $200.76	Hrs	x $46.72	Hrs	x $93.43	Cost
1	162	16,262	158	31,720	38	1,775	37	3,457	53,214
2	162	16,262	158	31,720	38	1,755	37	3,457	53,214
3	162	16,262	158	31,720	38	1,755	37	3,457	53,214
4	344	34,531	325	65,247	114	5,326	113	10,558	115,662
5	450	45,171	477	95,763	216	10,092	242	22,610	173,636
6	450	45,171	477	95,763	216	10,092	242	22,610	173,636
7	450	45,171	477	95,763	216	10,092	242	22,610	173,636
8	559	56,112	555	111,422	325	15,184	341	31,860	214,578
9	559	56,112	555	111,422	325	15,184	341	31,860	214,578
10	559	56,112	555	111,422	325	15,184	341	31,860	214,578
11	559	56,112	555	111,422	325	15,184	341	31,860	214,578
12	559	56,112	555	111,422	325	15,184	341	31,860	214,578
13	559	56,112	555	111,422	325	15,184	341	31,860	214,578
14	559	56,112	555	111,422	325	15,184	341	31,860	214,578
15	559	56,112	555	111,422	325	15,184	341	31,860	214,578
16	569	57,116	587	117,846	349	16,305	346	32,327	223,594
17	569	57,116	587	117,846	349	16,305	346	32,327	223,594
18	569	57,116	587	117,846	349	16,305	346	32,327	223,594
19	569	57,116	587	117,846	349	16,305	346	32,327	223,594
20	569	57,116	587	117,846	349	16,305	346	32,327	223,594
21	569	57,116	587	117,846	349	16,305	346	32,327	223,594
22	569	57,116	587	117,846	349	16,305	346	32,327	223,594
23	569	57,116	587	117,846	349	16,305	346	32,327	223,594
24	569	57,116	587	117,846	349	16,305	346	32,327	223,594
25	569	57,116	587	117,846	349	16,305	346	32,327	223,594
26	569	57,116	587	117,846	349	16,305	346	32,327	223,594
27	569	57,116	587	117,846	349	16,305	346	32,327	223,594
28	569	57,116	587	117,846	349	16,305	346	32,327	223,594
29	569	57,116	587	117,846	349	16,305	346	32,327	223,594
30	569	57,116	587	117,846	349	16,305	346	32,327	223,594

Table 4.16

Break-even Analysis and Storage Plan for Scenario B

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Demurrage		Grand	Cumulative		PW Value	Cumulative
Year	Hrs	x $250	Total	Value, i=0%	$(P/F_{8,n})$	(3) x (5)	PW value
1	0	0	53,214	53,214	.9259	49,271	49,271
2	0	0	53,214	106,428	.8573	45,620	95,341
3	0	0	53,214	159,642	.7938	42,241	137,582
4	3.1	775	116,437	276,079	.7350	85,581	223,163
5	22.5	5,625	179,261	455,340	.6806	122,005	345,168
6	22.5	5,625	179,261	634,601	.6302	112,970	458,138
7	22.5	5,625	179,261	813,862	.5835	104,599	562,737
8	56.3	14,075	228,653	1,042,515	.5403	123,541	686,278
9	56.3	14,075	228,653	1,271,168	.5002	114,372	800,650
10	56.3	14,075	228,653	1,499,821	.4632	105,912	906,562
11	56.3	14,075	228,653	1,728,474	.4289	98,069	1,004,631
12	56.3	14,075	228,653	1,957,127	.3971	90,798	1,095,429
13	56.3	14,075	228,653	2,185,780	.3677	84,076	1,179,505
14	56.3	14,075	228,653	2,414,433	.3405	77,856	1,257,361
15	56.3	14,075	228,653	2,643,086	.3152	72,071	1,329,432
16	55.1	13,775	237,369	2,880,445	.2919	69,288	1,398,720
17	55.1	13,775	237,369	3,117,824	.2703	64,161	1,462,881
18	55.1	13,775	237,369	3,355,193	.2502	59,390	1,522,271
19	55.1	13,775	237,369	3,592,562	.2317	54,998	1,577,269
20	55.1	13,775	237,369	3,829,931	.2145	50,916	1,628,185
21	55.1	13,775	237,369	4,067,300	.1987	47,165	1,675,350
22	55.1	13,775	237,369	4,304,669	.1839	43,652	1,719,002
23	55.1	13,775	237,369	4,542,038	.1703	40,424	1,759,426
24	55.1	13,775	237,369	4,779,407	.1577	37,433	1,796,859
25	55.1	13,775	237,369	5,016,776	.1460	34,656	1,831,515
26	55.1	13,775	237,369	5,254,145	.1352	32,092	1,863,607
27	55.1	13,775	237,369	5,491,514	.1252	29,719	1,893,326
28	55.1	13,775	237,369	5,728,883	.1159	27,511	1,920,837
29	55.1	13,775	237,369	5,966,252	.1073	25,470	1,946,307
30	55.1	13,775	237,369	6,203,621	.0994	23,594	1,969,901

B, the first silo should be built between years 12 and 30, and the second, no sooner than the twenty-first year.

The results of this analysis may not be appropriate for a mine which has characteristics which are different from the one used as a model in this study. They also may not be appropriate for a mine which uses criteria other than cost to decide when to build additional storage. For example, suppose that managment is concerned about the percentage of weekends worked by the crews which fill the silo(s) and load the trains. If this percentage rises above some maximum acceptable level, then management may decide that storage needs to be added, additional crews added, or both. For example, mine management's policy may not allow the workers to be on call for more than 1 in 4 weekends. Using this as a decision criteria suggests that a second silo be built by the sixth year in Scenario A and by the fourth year in Scenario B, when the percentage of weekends worked by the silo labor crews begins to exceed 25%. Table 4.17 shows the percentage of available weekend hours which are worked by the 2 types of crews for Scenarios A and B. Total available weekend hours are 2400, derived by multiplying the number of weekends worked (50) times the number of hours in a weekend (48).

The next chapter shows how to modify the model to suit a

Table 4.17

Percentage of Weekends Worked by Each Crew in Scenarios A and B

	Scenario A		Scenario B	
Year	Silo Labor	Train Labor	Silo Labor	Train Labor
1	4.6	1.9	13.3	3.1
2	11.5	4.9	13.3	3.1
3	21.8	12.4	13.3	3.1
4	21.8	12.4	27.9	9.5
5	21.8	12.4	38.6	19.1
6	28.4	18.5	38.6	19.1
7	34.8	25.8	38.6	19.1
8	34.8	25.8	46.4	27.8
9	34.8	25.8	46.4	27.8
10	34.8	25.8	46.4	27.8
11	38.5	30.3	46.4	27.8
12	38.5	30.3	46.4	27.8
13	38.5	30.3	46.4	27.8
14	38.5	30.3	46.4	27.8
15	38.5	30.3	46.4	27.8
16	46.4	42.9	48.2	29.0
17	36.1	22.7	48.2	29.0
18	36.1	22.7	48.2	29.0
19	36.1	22.7	48.2	29.0
20	36.1	22.7	48.2	29.0
21	38.2	24.4	48.2	29.0
22	38.2	24.4	48.2	29.0
23	38.2	24.4	48.2	29.0
24	38.2	24.4	48.2	29.0
25	38.2	24.4	48.2	29.0
26	38.2	24.4	48.2	29.0
27	40.9	25.0	48.2	29.0
28	40.9	25.0	48.2	29.0
29	40.9	25.0	48.2	29.0
30	40.9	25.0	48.2	29.0

particular operation. Even for a mine which does have similar features, there are some important caveats which should be heeded. These caveats are presented in Chapter 6, followed by instructions on how to modify the simulation programs to reflect different operational features.

CHAPTER 5

CAVEATS AND INSTRUCTIONS FOR MODIFICATIONS TO THE SIMULATION MODEL

5.1 Caveats

As in any scientific study, there are appropriate and inappropriate uses of its results. This model was developed for use as a long-range planning tool, but the assumptions were based on past behavior of the coal markets served by the mines in the Eastern Powder River Basin and expected future behavior of those coal markets. Because this model is a microeconomic model, it cannot account for macroeconomic effects which would change expected future behavior of the coal markets. For predictions 10 years into the future, its results should be carefully scrutinized because they may not be accurate. It is highly recommended, therefore, that users of this model run this model at least once a year, changing parameters as perceptions about the future change. Some parameters which might be changed are the interest rate, labor rates, demurrage costs, the capital cost of a silo, and expected annual tonnage shipped.

This model used cost criteria to determine when to build

an additional silo. Other criteria may be more appropriate for some operations. For example, demurrage may be a constraining factor. In that case, the simulation model should be run until the maximum acceptable level of demurrage is reached, and then a silo should be added. Additional simulation runs should be made until this maximum is again reached, and so on. Labor criteria, in terms of hours worked on Saturday and Sunday, may be a constraining factor. In both of these cases, this model should be studied carefully and modified so that the most accurate information about labor and demurrage is obtained.

If silos are used for blending, this model is inappropriate, for major modifications should be made to accommodate blending. This model, however, can still be used by mines if there are minor operational differences, such as plant throughput, expected demand (in terms of trains per day), or number of silos. These modifications are discussed in the next section.

5.2 Instructions for Modifying the Model

In order to change this simulation model to represent a different type of operation, a general understanding of how the simulation model works is necessary. This section will

present a general overview of the model but will not discuss line-by-line details of the simulation model.

Two types of simulation models were developed: the base case model with one silo, and an alternate case with more than one silo. The base case model will be discussed first, and the alternate model will be presented in terms of the differences between it and the base case.

5.2.1 Base Case Model

For this discussion of the base case model, refer to the program listing in Appendix 2. There are 2 major portions to this model, the FORTRAN code, run on the FORTRAN G compiler and the SLAM code, run on an IBM 3033. The FORTRAN code can be divided into 3 portions: the main code, lines 1 through 14; the USERF code, lines 17 through 33; and the STATE code, lines 36 through 46. When a job is run, the job control language (JCL) calls up the main code in the FORTRAN subroutine. This main code defines variables which are shared by both the FORTRAN code and the SLAM code, defines files and file sizes, and calls up the SLAM code on line 12. In turn, the SLAM code calls up the other 2 parts of the FORTRAN code as needed. Figure 5.1 shows a simple flow chart of how the JCL, FORTRAN, and SLAM code work together.

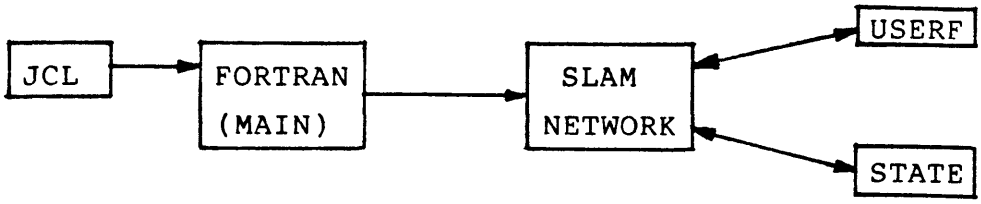

Figure 5.1

Flow Chart of Computer Simulation Model

The USERF portion of the FORTRAN code is a user-defined function which calculates the time between train arrivals. The number of train arrivals per day is generated from the Poisson distribution (line 25) and converted to hours between arrivals (lines 26 through 32). The SLAM network then reads this information from USERF as it is needed.

The STATE portion of the FORTRAN code serves as an interface between the continuous part of the model and the SLAM network. When an event occurs in the SLAM network, it calls up the STATE subroutine which then calculates the value of ss(1) which measures and controls the amount of coal in the silo(s) as the silo(s) are dumped or filled. This STATE subroutine is constantly monitored by DETECT networks in the simulation model to detect when silos are full or empty.

Just as the FORTRAN code can be divided into 3 separate

portions, so can the SLAM code. The first portion, lines 1 through 41, lies outside the major network. This portion sets up the initial conditions of the network and defines the different variables used in the simulation model. The actual network then begins on line 42.

The second portion is the "day of the week model" from lines 47 through 70. This model tells the rest of the model when it is Saturday, Sunday, or a weekday by setting flags for different variables depending on the day of the week. These flags are needed to collect weekend labor information.

The third portion of the model is the train model, from lines 74 through 114. An entity, or train, is created and assigned an arrival time on line 76 based on USERF in the FORTRAN code. The entity then waits for its arrival time to occur. When its arrival time comes up, the entity copies itself and branches back to line 74 to create another entity and moves forward into the mine. If the mine is already full, i.e., there is one train in the mine and one waiting, the entity is destroyed. This action was taken because, according to one source in the Eastern Powder River Basin, there is usually at least 1 hour between train arrivals under normal circumstances (Ausland, 1984). If the situation arose where one train was in the mine and one waiting, the mine would probably call the Burlington

Northern and ask them to hold the train.

The statements on lines 83 through 86 collect statistics for the time between train arrivals and the number of arrivals. As the train arrives at the mine, the "demurrage clock" is started when ATRIB(2) is set to equal the current time, or "TNOW." The next 4 statements following the ASSIGN node collect information about when trains arrive on the weekend. This information is used to construct the histogram, "time into weekend" which was discussed in Chapter 4.

The train then waits for an available silo at the AWAIT node on line 93. The flag to empty the silo, xx(5), is set to 1 so that the silo can be emptied into the train (line 95). The variable xx(19) is set to TNOW to mark the start time of filling the train. After the train is filled, another variable xx(20), calculates the total time it took to fill the train by subtracting xx(19), the start time, from TNOW, the finish time. This calculation occurs on line 143.

The train is filled according to the statement on line 96. This statement monitors the EMPT node in the DETECT portion of the train model on line 136. This DETECT portion monitors the state of the silo to determine when the silo has been emptied, i.e. when it has passed the 500 ton

threshold. When the silo is empty, this model assumes that the train is filled since only one silo exists. This logic, of course, does not hold true if there is more than one silo because a train can be full when there is still coal in a silo. This assumption is the major difference between this case and the "n silo case," discussed in section 5.2.2.

After the train is filled on line 96 (which works in conjunction with the DETECT network on lines 136 through 155), the silo is freed up so it can be refilled (line 97). Line 99 counts one less train in the mine, and line 100 calculates how long the train was in the mine. Lines 101 and 102 collect demurrage information for all days of the week and for the weekend, using the flags assigned in the "day of the week" model. Lines 104 through 114 then collect statistics on the items listed and make histograms for demurrage (weekends and all days), and "time into weekend."

The 2 DETECT networks constantly monitor ss(1) in the STATE subroutine to determine when the silo is full or empty. When ss(1) crosses a threshold value of 10,500 or 500, then the statements in the DETECT networks are executed. The DETECT network on lines 136 through 155 control the emptying of the silo and filling of the train. On line 136 when ss(1) has crossed 500, the silo is empty and the train full. On lines 138 and 139, flags are set to

stop emptying the silo and to start filling it. Line 140 resets the value for the train fill rate which is uniformly distributed between 9990 and 10,010. Lines 142 through 148 collect information on the length of time to fill the train on Saturdays and Sundays and lines 149 through 154 collect statistics on the time to fill the train, and the total number of hours spent annually filling the train on Saturdays and Sundays. This DETECT network ends on line 155.

The other DETECT network on lines 118 through 138 controls the filling of the silo and detects when the silo is full by measuring when ss(1) crosses the upper threshold value of 10,500. Line 121 controls the fillng of the silo at the specified rate. The remainder of the network collects statistics on how long it took to fill the silo on Saturdays and Sundays.

The last portion of the SLAM model on lines 159 through 165 is the "downtime model." The program comments are fairly explanatory. First, an entity is created and a time before the first failure assigned per the uniform distribution with lower and upper bounds of 5 and 55 hours, respectively (line 160). The number 4 in this statement identifies the random-seed stream which will be used to generate the time before the first failure. When a failure

occurs, production goes down so the silo fill rate, xx(7), is set to 0. The plant is down from 2 to 8 hours, specified on line 162, and when it comes up, the silo fill rate is set back to normal. The time between subsequent failures is uniformly distributed between 15 and 45 hours. As these subsequent failures occur, xx(7) is again set to 0, and the loop continues.

The SLAM portion of this model does not work in a sequential fashion, but a concurrent one. At time 0, the "day of the week model," the "train model," and the "downtime model" all start, along with the FORTRAN subroutine to make up the model in its entirety. Because of nuances associated with simulation programming, if a reader wants to make major structural changes in this program, he or she should consult the book on SLAM (Pegden and Pritsker, 1984).

The simplest types of changes to make are changes in parameters, such as the number of train arrivals per day, silo fill rate, train fill rate, time between plant failures, duration of plant failures, and random seed streams. To change the average number of train arrivals per day, change xx(21) on line 12 to the desired number of average daily train arrivals. This value of xx(21) is read into the FORTRAN subroutine on line 24, which then generates

time between arrivals. The parameters associated with train arrivals in the FORTRAN subroutine will probably also need to be changed. These parameters are on lines 27, 28, and 31 in the FORTRAN subroutine. They are: the factor for ALO, which is .25 on line 27; the factor for AHI, which is 1.1 on line 28; and the parameters of the uniform distribution when the number of train arrivals in a day is equal to zero (line 31). These parameters were discussed in Chapter 4.

To change the silo fill rate, change the parameters associated with xx(7) in each place that xx(7) occurs. For example, if the silo fill rate needed to be changed to 4000 tph, xx(7) on line 11 should read "xx(7) = 4000." If the actual silo fill rate is variable, ranging from 3500 to 4100 tph, then the other lines which should be changed are lines 121 and 163 to read

"xx(7)=UNFRM(3500,4100,x)" and
"ASSIGN,XX(7)=UNFRM(3500,4100,x)," respectively.

The "x" is the random number seed stream. This random seed stream number also appears on lines 140, 160, 162 and 164, and should range from 1 to 9. It appears in the USERF portion of the FORTRAN subroutine on lines 25, 29, and 31, as well. Similarly, the train fill rate can be changed by

changing parameters associated with xx(6).

The downtime model is very simple to change. It may be interesting to change the distributions in the downtime model as well as the durations and time between failures to see what effects these changes have on demurrage and labor. For example, suppose that the downtime records indicate that the time between failures is uniformly distributed between 24 and 96 hours, the duration of the downtime is triangularly distributed between 1 and 10 hours, and that no information is available on the time before the first failure, so it will be assumed that it is the same as the time between failures. Suppose also that the silo fill rate is uniformly distributed between 3800 and 4100. Then lines 160 through 164 in the downtime model would be rewritten as follows:

```
            ACT,UNFRM(24,96,1);
DOWN        ASSIGN, xx(7)=0;
            ACT,TRIAG(1,10,1);
            ASSIGN,xx(7)=UNFRM(3800,4100,1);
            ACT,UNFRM(24,96,1),,DOWN;
```

Another change which would easily be made is the way in which the time between train arrivals is calculated. For example, suppose that the time between arrivals is uniformly distributed between 3 and 24 hours. To change the existing model, one should delete the USERF portion of the FORTRAN

subroutine and replace lines 74 through 81 in the SLAM code with these 2 statements:

```
CREATE,UNFRM(3,24,1),0,,1500,1;
ACT;
```

5.2.2 The Case with More Than One Silo

The differences between this model which handles more than one silo and the base case is in the STATE subroutine and the DETECT networks. This difference is needed because the base case with 1 silo assumed that when the silo was empty, the train was full. This situation was handled with 1 DETECT node. (Another DETECT node detected when the silo was full.) Such an assumption does not hold for more than 1 silo, so a third DETECT node was included. One, of course, detects when the silos are full. A second detects when at least 1 silo is empty, and a third detects when the train is full. Therefore, this case introduces another state variable, ss(2), which measures the amount of coal in the train. The STATE subroutine is modified to include this additional state variable. Program listings for this case are in Appendix 3.

When an event occurs, the STATE subroutine recalculates the values of ss(1) and ss(2). Again, the DETECT networks constantly monitor ss(1) and ss(2) to detect when threshold

values have been crossed. In the SLAM model, these DETECT networks are on lines 119 through 135, 137 through 143, and 147 through 162.

The first network detects when a silo is full. Note that this threshold is set at 30,500 because this particular example represents a 3-silo case. For a 2-silo case, this number would be 20,500. For the 4-silo case, it would be 40,500, and so on.

The second DETECT network monitors to see when at least one silo is empty so that it can be filled, regardless of whether a train is in the mine being filled by another silo. The threshold value, 20,500 in this case, is calculated by taking the total number of silos, (n) less 1 silo (n-1), times 10,000, and adding 500, demonstrated in this simple equation:

$$(n-1)(10,000) + 500$$

The last DETECT network, lines 147 through 162, detects when the train is full. The train is filled according to the statement on line 98 which monitors the TFUL node on line 147. This works in the same way as the base case, in which the train was filled according to the statement on line 96 which monitored the EMPT node.

This model can be modified the same way as the base case model, changing the number of train arrivals, silo and train fill rates, and downtime parameters. In additiion, this model can be modified to handle as many silos as desired. To do so, the capacity of the silo storage must be changed as well as the threshold values in the DETECT nodes.

The first change would be on line 9. The variable ss(1) should be equal to the number of silos times the capacity plus some variability. In this case with 3 silos with a live capacity of 10,000 tons plus 500 tons of buffer, total capacity is 30,500. For 2 silos, it would be 20,500, and for 4, 40,500. Another modification must be made on line 119 and agree with the modification on line 9. Also, the threshold value on line 137 should be changed according to the formula, (n-1)(10,000) + 500, where n = number of silos.

If any major modifications need to be made, consult Introduction to Simulation and Slam, Second Edition (Pegden and Pritsker, 1984). Another good source may be the program listings from the University of Wyoming study (Bradley, et al., n.d.).

Suggestions for major modifications will be briefly discussed in Chapter 6 which also summarizes this study, presents the results, and draws conclusions.

CHAPTER 6

RESULTS, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

6.1 Summary, Results, and Conclusions

The purpose of this study was to develop a storage plan for the life of a mine representative of the Eastern Powder River Basin. Two scenarios were developed: Scenario A with a maximum annual output of 24 million tons per year and plant capacity of 6000 tons per hour; and Scenario B with a maximum annual output of 12 million tons per year and plant capacity of 3000 tons per hour. The annual output for the first 8 years in each of these cases was taken from historical data. To determine when to build additional silos, simulation models of the storage and loadout facilities were first developed. The output from this model, weekend labor hours and total annual demurrage, were evaluated in terms of annual cost. Each of these annual costs was multiplied by a present worth factor, using a discount rate of 8%. The year in which the sum of these annual discounted costs equaled the cost of a silo was the year in which the silo should be built. The results

obtained from this net present value technique were compared to the results obtained from the payback method in which annual costs were not discounted. Table 6.1 indicates the years in which a silo should be built based on both techniques for Scenario A and Scenario B.

Table 6.1

Years in which a Silo Should be Added

	Scenario A		Scenario B	
	Payback	NPV	Payback	NPV
Add 2nd silo	10	16	12	30
Add 3rd silo	16	26	21	--
Add 4th silo	23	--	29	--
Add 5th silo	29	--		

These results suggest that for Scenario A, the second silo should be added between years 10 and 16, and the third between years 16 and 26. The results of the NPV analysis do not recommend the addition of a fourth or fifth silo, although the payback method recommends the addition of a fourth silo in year 23 and a fifth in year 29.

For Scenario B, the results recommend the addition of a second silo between years 12 and 30. The results of the NPV analysis recommend that no more than 2 silos be constructed, but the payback method recommends the addition of a third

and fourth silo in years 21 and 29, respectively.

These results, based solely on weekend labor cost and demurrage cost, sugggest that the mines in the Eastern Powder River Basin have overinvested in storage capacity. Table 6.2 shows the design capacity (productive capacity the loadout facilities were designed to handle), permitted capacity, and the number of silos and/or slots for selected mines in the Eastern Powder River Basin (Jones, 1985).

This table suggests that, based on costs, these mines have all overinvested in loadout facilities. Jacobs Ranch may be an exception since their silos are also used for blending.

6.2 Recommendations for Future Research

Labor and demurrage costs could be affected by changing several different aspects of this model. One recommendation for further research is to change assumptions to measure their effect on labor and demurrage. The assumptions which could be changed are

1. Work schedule
2. Type of storage facility
3. Plant downtime
4. Number of rail loops

Table 6.2

Capacities and Storage for Selected Mines in the Eastern Powder River Basin

Company	Mine Name	Capacity (MTPY) Design	Capacity (MTPY) Permit	1984 Production (MTPY)	Number of Silos or Slots
Amax	Belle Ayr	25.0	25.0	13.4	4 silos
Amax	Eagle Butte	29.0	29.0	13.4	4 silos
Carter	Caballo	5.0	7.0[1]	8.2	4 silos
Cordero	Cordero	24.0	13.5	10.4	4 silos, 1 slot
Kerr-McGee	Jacobs Ranch	14.5	14.5	14.4	7 silos[2]
Mobil	Caballo Rojo	15.0	15.0	3.4	2 silos
Thunder Basin	Black Thunder	20.0	20.0	21.2	2 silos, 1 slot

[1]Expected to increase to 10.0 in 1986 and 12.0 in 1987

[2]Silos are also used for blending.

The work schedule in this model was 8-3-5. If this schedule was changed to, say, an 8-2-5 schedule, then how much overtime would be required and would it affect the overtime worked on weekends?

What effects would the type of storage facility chosen have on the storage plan? For instance, how different would the storage plan look if slot storage or off-track silos were built instead of over-the-track silos? How much labor and demurrage would be incurred in this case?

How does plant downtime affect a storage plan? What are the effects of different distributions of downtime on the storage plan? How do preventive maintenance and unexpected downtime each affect a storage plan?

What effect does the number of rail loops have on a storage plan? How does it affect the number of facilities needed and what effect does it have on cost of the storage plan?

Another aspect of this model which could more easily be investigated is the tradeoff between labor and demurrage. How much labor must be used to prevent demurrage? What kind of relationship exists between labor and demurrage? Is it linear, exponential, or something different?

Finally, a more difficult undertaking would be to develop a model which accommodates coal blending. What

effect does coal blending have on a storage plan? Does the plan differ for different types of storage and loadout facilities? If so, how much?

It should be apparent that this study has barely scratched the surface on issues surrounding storage and loadout facilities and operations. There are many more aspects which need to be studied, especially by the public sector. Hopefully, this study has provided some insight into potential solutions to problems involving storage and loadout and contributed to both the industrial and academic communities, laying some groundwork for further study in this area.

REFERENCES CITED

Ausland, Pete. 1984-85. Ph.D. candidate, Mining Engineering Department, Colorado School of Mines.

Bradley, Charles E., Wayne I. Gray, and Sam G. Taylor. n.d. "Sizing Storage Facilities for Open Pit Coal Mines." University of Wyoming Industrial Fund, Laramie, Wyoming.

Cahill, Glenn. 1985. McNally-Pittsburgh, January 31.

Dewey, Roger. 1984-85. Ph.D. candidate, Mining Engineering Department, Colorado School of Mines.

Durham, Mary, and Julie Gwinn. 1982. "Preliminary Study of Storage and Loadout Facilities at Mobil's Caballo Rojo Mine." July. Colorado School of Mines. Golden, Colorado.

Glass, Gary. 1985. State Geologist, Wyoming Geological Survey, March 25.

Jones, Richard W. 1985. Staff Coal Geologist, Wyoming Geological Survey, March 25.

Keystone Coal Industry Manuals, 1972-1984.

Mayo, Tom. 1984. Coordinator of Distribution, Sales, and Services, Exxon Coal, December 10.

McFarlend, Gary. 1984-85. Manager, Transportation and Distribution, SUNEDCO Coal Company, December 4 and February 8.

Mueller, Jerry K. 1977. "Silo vs. Barn Type Storage for Coal." Mining Congress Journal, vol. 63, pp. 64-66.

Office of Technology Assessment. 1981. An Assessment of Development and Production Potential of Federal Coal Leases, December. p. 175.

Pegden, Claude Dennis, and A. Alan B. Pritsker. 1984. Introduction to Simulation and SLAM. Second Edition. New York. John Wiley and Sons, Inc.

Peterson, Rein, and Edward Silver. 1979. Decision Systems for Inventory Management and Production Planning. New York. John Wiley and Sons, Inc., pp. 598-608.

Rowe, Anne. 1985. Evaluation Engineer, Thunder Basin Coal Company, March 5.

Ryan, Thomas A., Jr., Brian L. Joiner, Barbara F. Ryan. 1981. Minitab Reference Manual. Boston: Duxbury Press.

ADDITIONAL READINGS

Chu, Jean, and Michael Ermolowich. 1980. "Determining the Optimum Size of a Coal Silo" Simulation, December, vol. 35, pp. 191-197.

Cohen, Kalman J., and Richard M Cyert. 175. Theory of the Firm: Resource Allocation in a Market Economy. Prentice-Hall, New Jersey.

Gould, J.P., and C.E. Ferguson. 1980. Microeconomic Theory. Richard D. Irwin, Inc., Illinois.

Hansen. 1979. "Planning for Efficient Unit Train Unloading." Power Engineering, vol. 83, pp. 51-54.

Lahey, J.P. 1979. "Optimizing Storage Capacities Within a Coal Preparation Facility by a Computer Simulation." Journal of Engineering for Industry, vol. 101, pp. 223-229.

Lorentzen. 1981. "Transportation of Western Coal." Mining Congress Journal, vol. 65, pp. 35-37.

APPENDIX 1

ALTERNATIVE METHODS OF CALCULATING DEMURRAGE

There are 2 other techniques which could be used to calculate demurrage which will certainly boost this $250 per hour figure. One is to amortize the entire cost of the train over a 5-or 10-year period, or whatever length of time is appropriate, and convert this figure into an hourly rate, adding it to the $250 per hour figure. (The $250 per hour is only the demurrage cost of the locomotives and not the rest of the train.) For example, if a train car costs $50,000, 100 train cars cost $5,000,000. Straight-line amortization over 10 years is

$$\$5,000,000/10 = \$500,000 \text{ per year.}$$

In one year there are

$$(365 \text{ days/year}) \times (24 \text{ hours/day})$$
$$= 8,760 \text{ hours per year.}$$

Therefore, the hourly cost of the train, excluding

locomotives, is

($500,000 per year)/(8760 hours per year)
= $57.08 per hour.

So, the cost of demurrage in this case is

$250 + $57.08 = $307.58.

A second method of calculating the cost of delaying a train is to calculate the cost of lost revenues, regardless of the 4 hour grace period. For example, suppose that a cycle is 10 days, or 240 hours. This train can make

(355 days per year x 24 hours per day)/(24 hours per trip)
= 35.5 trips per year.

Assume that the train will probably make 35 trips per year with a half-day buffer. If delays at the mine cause the cycle time to increase by 10 hours, up to 250 hours, the total number of trips the train can make is

(8520 hours per year)/(250 hours) = 34.1 trips.

This reducton in the total number of trips which can be made by one train results in a loss of 10,000 tons to both the mine and the utility. If the utility's loss is significant, they may be forced eventually to buy another unit train. of course, the mine loses out on the revenues which would have been generated by the coal sale, especially if the utility decides to buy coal from another company in the future.

the cost of these delays can also be expressed in terms of revenues lost per cycle. for example, suppose that for a 240 hour cycle, the mine delays the train for 4 hours more than some acceptable minimum level. then the mine has lost revenues for 1/60 of a cycle, i.e.,

4 hour delay/240 hour cycle = 1/60 of a cycle lost.

The mine sells 10,000 tons per cycle at a specific price per ton. (For illustration purposes, assume this price is $4 per ton.) The revenues lost by the mine are

(1/60 of a cycle) x (10,000 tons/cycle) x ($4/ton)
= $666.67.

Figure A.1 shows the linear relationship between revenues lost and hours of delay. These hours of delay represent

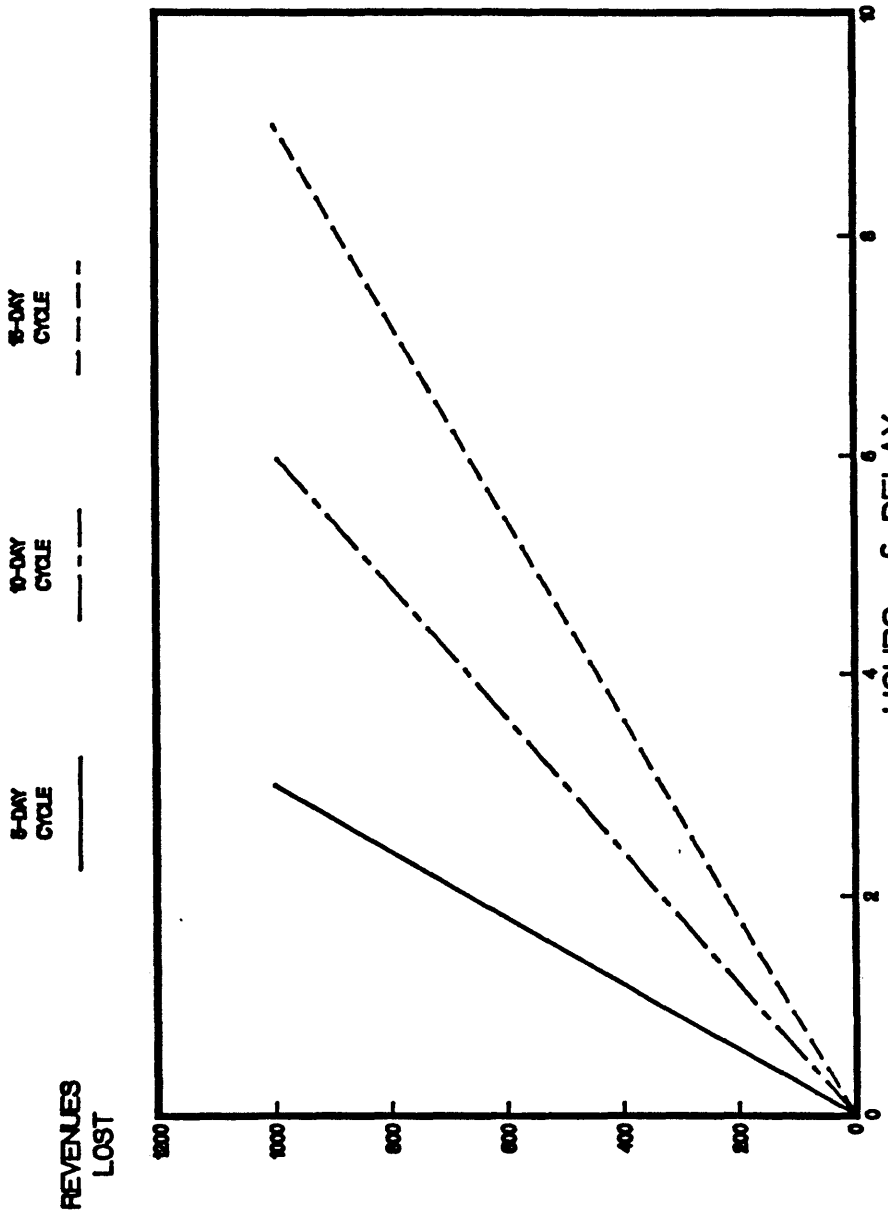

Figure A.1

Revenues Lost because of Train Delays

delays which are greater than some minimum acceptable level which would not increase the cycle time. The price per ton of coal is assumed to be $4.

APPENDIX 2

PROGRAM LISTINGS FOR BASE CASE

Fortran Subroutine

```
      DIMENSION NSET(100000)                                              0001
      COMMON /XCOM1/ MFE(100),MLE(100),NQ(100)                            0002
      COMMON /SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,                0003
     1               MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,             0004
     2               NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)            0005
      COMMON QSET(100000)                                                 0006
      EQUIVALENCE (NSET(1),QSET(1))                                       0007
      NNSET =100000                                                       0008
      NCRDR = 5                                                           0009
      NPRNT = 6                                                           0010
      NTAPE = 7                                                           0011
      CALL SLAM                                                           0012
      STOP                                                                0013
      END                                                                 0014
                                                                          0015
                                                                          0016
      FUNCTION USERF(I)                                                   0017
      COMMON /SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,                0018
     1               MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,             0019
     2               NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)            0020
C                                                                         0021
C     ALAMDA IS THE LAMDA PARAMATER OF THE POISSON RANDOM NO. GENER       0022
C                                                                         0023
      ALAMDA=XX(21)                                                       0024
 30   ATRIB(4)=NPSSN(ALAMDA,2)                                            0025
      IF(ATRIB(4) .EQ. 0.) GO TO 10                                       0026
      ALOW=(24.0/ATRIB(4))*.25                                            0027
      AHI=(24.0/ATRIB(4))*1.1                                             0028
      USERF=UNFRM(ALOW,AHI,2)                                             0029
      GO TO 20                                                            0030
 10   USERF=UNFRM(24.,28.,2)                                              0031
 20   RETURN                                                              0032
      END                                                                 0033
                                                                          0034
                                                                          0035
      SUBROUTINE STATE                                                    0036
      COMMON /SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,                0037
     1               MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,             0038
     2               NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)            0039
2     IF(XX(1).NE.1) GO TO 5                                              0040
4     SS(1)=SSL(1)+DTNOW*XX(7)                                            0041
      GO TO 7                                                             0042
5     IF(XX(5).NE.1.OR.XX(1).NE.0) GO TO 7                                0043
6     SS(1)=SSL(1)-DTNOW*XX(6)                                            0044
7     RETURN                                                              0045
      END                                                                 0046
```

SLAM Program Listing

```
  1  GEN, MARTY CAUDILL,:  BASE CASE  ,06,05,85,1;
  2  LIM,1,4,10000;                        MAX NO. FILES,ATTRIBUTES,ALL ENTRIES
  3  ;                                     MNTRY(=NNSET/(MATR+4)
  4  ;                                     ATRIB(1)=TIME BETWEEN ARRIVALS
  5  ;                                     ATRIB(2)=TIME ENTERING SCALE
  6  ;                                     ATRIB(3)=INDIVIDUAL DEMURRAGE
  7  ;                                     ATRIB(4)=NUMBER OF ARRIVALS PER DAY
  8  CON,0.2,,,,.5;
  9  INTLC,SS(1)=10500,
 10        XX(6)=10000,
 11        XX(7)=3000,
 12        XX(21)=3.00;
 13  ;                                     SS(1)=AMT IN SILO
 14  ;                                     XX(1)=SILO FILLING FLAG/ 0=FULL, 1=FILL
 15  ;                                     XX(2)=WEEK/WEEKEND FLAG/ 1=WEEKEND, 0=WEEKDAY
 16  ;                                     XX(3)=NUMBER OF TRAINS IN MINE
 17  ;                                     XX(4)=TOTAL NUMBER OF ARRIVALS ON WEEKENDS
 18  ;                                     XX(5)=SILO EMPTYING FLAG/ 0=DONT, 1=EMPTY
 19  ;                                     XX(6)=TRAIN FILL RATE
 20  ;                                     XX(7)=SILO FILL RATE
 21  ;                                     XX(8)=TIME INTO WEEKEND
 22  ;                                     XX(9)=SAT FLAG/ 1=SAT, 0=NOT SAT
 23  ;                                     XX(10)=SUN FLAG/ 1=SUN FLAG, 0=NOT SUN
 24  ;                                     XX(11)=WEEKEND MARKTIME
 25  ;                                     XX(12)=TIME START FILLING SILO
 26  ;                                     XX(13)=TIME SPENT FILLING SILO
 27  ;                                     XX(14)=
 28  ;                                     XX(15)=TIME SPENT FILLING SILO ON SAT
 29  ;                                     XX(16)=TOTAL TIME SPENT FILLING SILO ON SAT
 30  ;                                     XX(17)=TIME SPENT FILLING SILO ON SUN
 31  ;                                     XX(18)=TOTAL SPENT FILLING SILO ON SUN
 32  ;                                     XX(19)=TIME START FILLING TRAIN
 33  ;                                     XX(20)=TIME SPENT FILLING TRAIN
 34  ;                                     XX(21)=LAMDA PARAMETER FOR POISSON
 35  ;                                     XX(22)=TIME SPENT FILLING TRAIN ON SAT
 36  ;                                     XX(23)=TOTAL SPENT FILLING TRAIN ON SAT
 37  ;                                     XX(24)=TIME SPENT FILLING TRAIN ON SUN
 38  ;                                     XX(25)=TOTAL SPENT FILLING TRAIN ON SUN
 39  ;                                     XX(26)=TEMPORARY VARIABLE
 40  ;                                     XX(27)=TOTAL OF WEEKEND DEMURRAGE
 41  INIT,0.8500;
 42  NET;
 43        RESOURCE/S01(1),1;              SILO 1
 44
 45
 46
 47        CREATE,,0,,1,1;                 WEEKEND/WEEKDAY MODEL
 48        ACT;
 49  MOND  ASSIGN,XX(2)=0,XX(10)=0,
 50              XX(9)=0;                  MON
 51        ACT,24;
 52        ASSIGN,XX(2)=0,XX(10)=0,
 53              XX(9)=0;                  TUE
 54        ACT,24;
 55        ASSIGN,XX(2)=0,XX(10)=0,
 56              XX(9)=0;                  WED
 57        ACT,24;
 58        ASSIGN,XX(2)=0,XX(10)=0,
 59              XX(9)=0;                  THU
 60        ACT,24;
 61        ASSIGN,XX(2)=0,XX(10)=0,
```

```
62              XX(9)=0;                FRI
63        ACT,24;
64        ASSIGN,XX(2)=1,XX(10)=0,
65               XX(9)=1,
66               XX(11)=TNOW;           SAT
67        ACT,24,
68        ASSIGN,XX(2)=1,XX(10)=1,
69               XX(9)=0;                SUN
70        ACT,24,,MOND;
71
72
73
74  STRT  CREATE,,0,,,1;                  CREATE ONE TRAIN ENTITY
75        ACT;
76        ASSIGN,ATRIB(1)=USERF(1);       OBTAIN INTERARRIVAL TIME FROM USERF
77        ACT,ATRIB(1);                   TIME BETWEEN ARRIVALS
78        GOON;
79        ACT,,,STRT;                     LOOP BACK TO GENERATE NEW ENTITY
80        ACT;
81        GOON;
82        ACT,,XX(3).LE.1;                DESTROY ENTITY IF MINE FULL
83        COLCT,ATRIB(1),TIME B ARRIVALS,30,1,1;
84        ACT;
85        COLCT,ATRIB(4),NUMBER ARRIVALS,15,0,1;
86        ACT;
87        ASSIGN,ATRIB(2)=TNOW,
88               XX(4)=XX(4)+XX(2),
89               XX(8)=TNOW-XX(11),
90               XX(3)=XX(3)+1,
91               XX(8)=XX(8)*XX(2);     TRAIN ARRIVES AT MINE
92        ACT;
93        AWAIT(1),S01/1,1;               WAIT FOR SILOS
94        ACT;
95        ASSIGN,XX(5)=1,XX(19)=TNOW;   OK TO FILL NOW
96        ACT/1,REL(EMPT);                FILL TRAIN
97        FREE,S01/1;                     FREE SILO
98        ACT;
99        ASSIGN,XX(3)=XX(3)-1,
100              ATRIB(3)=TNOW-ATRIB(2),
101              XX(26)=ATRIB(3)*XX(2),
102              XX(27)=XX(27)+XX(26); COLLECTS DEMURRAGE INFO
103       ACT;
104       COLCT,ATRIB(3),DEMURRAGE  ALL,30/0/.5;
105       ACT;
106       COLCT,XX(4),WEEKEND ARRIVAL;
107       ACT;
108       COLCT,XX(8),TIME INTO WKEND,48/0/1;
109       ACT;
110       COLCT,XX(26),WKEND DEMURRAGE,30/0/.5;
111       ACT;
112       COLCT,XX(27),T WKND DEMURRAGE;
113       ACT;
114       TERM;
115
116
117
118       DETECT,SS(1),XF,10500,100;  DETECTS WHEN SILO FULL
119       ACT;
120       ASSIGN,XX(1)=0,
121              XX(7)=UNFRM(2700,3300,2),
122              XX(13)=TNOW-XX(12),
123              XX(15)=XX(13)*XX(9),
```

```
124                 XX(16)=XX(16)+XX(15),
125                 XX(17)=XX(13)*XX(10),
126                 XX(18)=XX(18)+XX(17); XX(13) THRU XX(18) SILO VARIABLES
127         ACT;
128         COLCT,XX(13),TIME FILLIN SILO;
129         ACT;
130         COLCT,XX(16),TT FILL SILO SAT;
131         ACT;
132         COLCT,XX(18),TT FILL SILO SUN;
133         ACT;
134         TERM;
135
136 EMPT    DETECT,SS(1),XN,500,100;    DETECTS WHEN START FILLING SILO &TRAIN FILLED
137         ACT;
138         ASSIGN,XX(5)=0,
139                 XX(1)=1,
140                 XX(6)=UNFRM(9990,10010,2);
141         ACT,
142         ASSIGN,XX(12)=TNOW,
143                 XX(20)=TNOW-XX(19),
144                 XX(22)=XX(20)*XX(9),
145                 XX(23)=XX(23)+XX(22),
146                 XX(24)=XX(20)*XX(10),
147                 XX(25)=XX(25)+XX(24); XX(20) THRU XX(25) TRAIN VARIABLES
148         ACT;
149         COLCT,XX(20),TIME FILLIN TRAN;
150         ACT;
151         COLCT,XX(23),TT FILL TRAN SAT;
152         ACT;
153         COLCT,XX(25),TT FILL TRAN SUN;
154         ACT;
155         TERM;
156
157
158
159         CREATE,,0,,1,1;                 PRODUCTION DOWN TIME MODEL
160         ACT,UNFRM(5,55,2);              TIME BEFORE FIRST FAILURE
161 DOWN    ASSIGN,XX(7)=0;                 PRODUCTION DOWN
162         ACT,UNFRM(2,8,2);               DOWN TIME
163         ASSIGN,XX(7)=UNFRM(2700,3300,2),PRODUCTION UP
164         ACT,UNFRM(15,45,2),,DOWN;       TIME BETWEEN FAILURES
165         END;
166 FIN;
```

APPENDIX 3

PROGRAM LISTINGS FOR THE CASE WITH MORE THAN ONE SILO

Fortran Subroutine

```
      DIMENSION NSET(100000)                                            0001
      COMMON /XCOM1/ MFE(100),MLE(100),NQ(100)                          0002
      COMMON /SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,              0003
     1               MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,           0004
     2               NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)          0005
      COMMON QSET(100000)                                               0006
      EQUIVALENCE (NSET(1),QSET(1))                                     0007
      NNSET =100000                                                     0008
      NCRDR = 5                                                         0009
      NPRNT = 6                                                         0010
      NTAPE = 7                                                         0011
      CALL SLAM                                                         0012
      STOP                                                              0013
      END                                                               0014
                                                                        0015
                                                                        0016
      FUNCTION USERF(I)                                                 0017
      COMMON /SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,              0018
     1               MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,           0019
     2               NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)          0020
C                                                                       0021
C     ALAMDA IS THE LAMDA PARAMATER OF THE POISSON RANDOM NO. GENER     0022
C                                                                       0023
      ALAMDA=XX(21)                                                     0024
 30   ATRIB(4)=NPSSN(ALAMDA,4)                                          0025
      IF(ATRIB(4) .EQ. 0.) GO TO 10                                     0026
      ALOW=(24.5/ATRIB(4))*.35                                          0027
      AHI=(24.0/ATRIB(4))*1.25                                          0028
      USERF=UNFRM(ALOW,AHI,4)                                           0029
      GO TO 20                                                          0030
 10   USERF=UNFRM(24.,28.,4)                                            0031
 20   RETURN                                                            0032
      END                                                               0033
                                                                        0034
                                                                        0035
      SUBROUTINE STATE                                                  0036
      COMMON /SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,              0037
     1               MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,           0038
     2               NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)          0039
      IF(XX(1).EQ.1.AND.XX(5).EQ.1) GO TO 5                             0040
      IF(XX(1).EQ.1.AND.XX(5).EQ.0) GO TO 6                             0041
      IF(XX(1).EQ.0.AND.XX(5).EQ.1) GO TO 7                             0042
      GO TO 8                                                           0043
5     IF(SS(1) .LT. 500.) GO TO 9                                       0044
      SS(1)=SSL(1)-DTNOW*(XX(6)-XX(7))                                  0045
      SS(2)=SSL(2)+DTNOW*XX(6)                                          0046
      GO TO 8                                                           0047
9     SS(2)=SSL(2)+DTNOW*XX(7)                                          0048
      GO TO 8                                                           0049
6     SS(1)=SSL(1)+DTNOW*XX(7)                                          0050
      GO TO 8                                                           0051
7     SS(1)=SSL(1)-DTNOW*XX(6)                                          0052
      SS(2)=SSL(2)+DTNOW*XX(6)                                          0053
      GO TO 8                                                           0054
8     RETURN                                                            0055
      END                                                               0056
```

SLAM Program Listing

```
GEN, MARTY CAUDILL, THREE SILO CASE,05,14,85,1,Y,N,Y,N;
LIM,1,4,10000;                          MAX NO. FILES,ATTRIBUTES,ALL ENTRIES
;                                       MNTRY(=NNSET/(MATR+4)
;                                       ATRIB(1)=TIME BETWEEN ARRIVALS
;                                       ATRIB(2)=TIME ENTERING SCALE
;                                       ATRIB(3)=INDIVIDUAL DEMURRAGE
;                                       ATRIB(4)=NUMBER OF ARRIVALS PER DAY
CON,0,2,.0005,.005,.5;                  NO DERIVATIVES,2 STATE VARIABLES POSSIBLE
INTLC,SS(1)=30500,
      SS(2)=0,
      XX(6)=10000,
      XX(7)=6000,
      XX(21)=6.6;
;                                       SS(1)=AMT IN SILO
;                                       SS(2)=AMT IN TRAIN
;                                       XX(1)=SILO FILLING FLAG/ 0=FULL, 1=FILL
;                                       XX(2)=WEEK/WEEKEND FLAG/ 1=WEEKEND, 0=WEEKDAY
;                                       XX(3)=NUMBER OF TRAINS IN MINE
;                                       XX(4)=TOTAL NUMBER OF ARRIVALS ON WEEKENDS
;                                       XX(5)=SILO EMPTYING FLAG/ 0=DONT, 1=EMPTY
;                                       XX(6)=TRAIN FILL RATE
;                                       XX(7)=SILO FILL RATE
;                                       XX(8)=TIME INTO WEEKEND
;                                       XX(9)=SAT FLAG/ 1=SAT, 0=NOT SAT
;                                       XX(10)=SUN FLAG/ 1=SUN FLAG, 0=NOT SUN
;                                       XX(11)=WEEKEND MARKTIME
;                                       XX(12)=TIME START FILLING SILO
;                                       XX(13)=TIME SPENT FILLING SILO
;                                       XX(14)=
;                                       XX(15)=TIME SPENT FILLING SILO ON SAT
;                                       XX(16)=TOTAL TIME SPENT FILLING SILO ON SAT
;                                       XX(17)=TIME SPENT FILLING SILO ON SUN
;                                       XX(18)=TOTAL SPENT FILLING SILO ON SUN
;                                       XX(19)=TIME START FILLING TRAIN
;                                       XX(20)=TIME SPENT FILLING TRAIN
;                                       XX(21)=LAMDA PARAMETER FOR POISSON
;                                       XX(22)=TIME SPENT FILLING TRAIN ON SAT
;                                       XX(23)=TOTAL SPENT FILLING TRAIN ON SAT
;                                       XX(24)=TIME SPENT FILLING TRAIN ON SUN
;                                       XX(25)=TOTAL SPENT FILLING TRAIN ON SUN
;                                       XX(26)=TEMPORARY VARIABLE
;                                       XX(27)=TOTAL OF WEEKEND DEMURRAGE
INIT,0,8500;
NET;
      RESOURCE/S01(1),1;                SILO 1


      CREATE,,0,,1,1;                   WEEKEND/WEEKDAY MODEL
      ACT;
MOND  ASSIGN,XX(2)=0,XX(10)=0,
            XX(9)=0;                    MON
      ACT,24;
      ASSIGN,XX(2)=0,XX(10)=0,
            XX(9)=0;                    TUE
      ACT,24;
      ASSIGN,XX(2)=0,XX(10)=0,
            XX(9)=0;                    WED
      ACT,24;
      ASSIGN,XX(2)=0,XX(10)=0,
            XX(9)=0;                    THU
```

```
        ACT,24;
        ASSIGN,XX(2)=0,XX(10)=0,
               XX(9)=0;                 FRI
        ACT,24;
        ASSIGN,XX(2)=1,XX(10)=0,
               XX(9)=1,
               XX(11)=TNOW;             SAT
        ACT,24;
        ASSIGN,XX(2)=1,XX(10)=1,
               XX(9)=0;                 SUN
        ACT,24,,MOND;


STRT    CREATE,,0,,,1;                  CREATE ONE TRAIN ENTITY
        ACT;
        ASSIGN,ATRIB(1)=USERF(1);       OBTAIN INTERARRIVAL TIME FROM USERF
        ACT,ATRIB(1);                   TIME BETWEEN ARRIVALS
        GOON;
        ACT,,,STRT;                     LOOP BACK TO GENERATE NEW ENTITY
        ACT;
        GOON;
        ACT,,XX(3).LE.1;                DESTROY ENTITY IF MINE FULL
        COLCT,ATRIB(1),TIME B ARRIVALS,30,1,1;
        ACT;
        COLCT,ATRIB(4),NUMBER ARRIVALS,18,0,1;
        ACT;
        ASSIGN,ATRIB(2)=TNOW,
               XX(4)=XX(4)+XX(2),
               XX(8)=TNOW-XX(11),
               XX(3)=XX(3)+1,
               XX(8)=XX(8)*XX(2);       TRAIN ARRIVES AT MINE
        ACT;
        AWAIT(1),S01/1,1;               WAIT FOR SILOS
        ACT;
        ASSIGN,XX(5)=1,XX(19)=TNOW,
               ATRIB(3)=TNOW-ATRIB(2),
               XX(26)=ATRIB(3)*XX(2),
               XX(27)=XX(27)+XX(26);    OK TO FILL NOW
        ACT/1,REL(TFUL);                FILL TRAIN
        FREE,S01/1;                     FREE SILO
        ACT;
        ASSIGN,XX(3)=XX(3)-1,
               SS(2)=0;                 ONE LESS TRAIN IN MINE
        ACT;
        COLCT,ATRIB(3),DEMURRAGE  ALL,30/0/.5;
        ACT;
        COLCT,XX(4),WEEKEND ARRIVAL;
        ACT;
        COLCT,XX(8),TIME INTO WKEND,48/0/1;
        ACT;
        COLCT,XX(26),WKEND DEMURRAGE,30/0/.5;
        ACT;
        TERM;


        DETECT,SS(1),XP,30500,100;      DETECTS WHEN SILO FULL
        ACT;
        ASSIGN,XX(1)=0,
               XX(7)=UNFRM(5400,6600,3),
               XX(13)=TNOW-XX(12),
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124                 XX(15)=XX(13)*XX(9),
125                 XX(16)=XX(16)+XX(15),
126                 XX(17)=XX(13)*XX(10),
127                 XX(18)=XX(18)+XX(17); XX(13) THRU XX(18) SILO VARIABLES
128         ACT;
129         COLCT,XX(13),TIME FILLIN SILO;
130         ACT;
131         COLCT,XX(16),TT FILL SILO SAT;
132         ACT;
133         COLCT,XX(18),TT FILL SILO SUN;
134         ACT;
135         TERM;
136
137         DETECT,SS(1),XN,20500,100;   DETECTS WHEN AT LEAST ONE SILO EMPTY
138         ACT;
139         ASSIGN,XX(1)=1,
140                 XX(12)=TNOW,
141                 XX(6)=UNFRM(9990,10010,3);
142         ACT;
143         TERM;
144
145
146
147 TFUL    DETECT,SS(2),XP,10000,100;   DETECTS WHEN TRAIN FULL
148         ACT;
149         ASSIGN,XX(5)=0,
150                 XX(20)=TNOW-XX(19),
151                 XX(22)=XX(20)*XX(9),
152                 XX(23)=XX(23)+XX(22),
153                 XX(24)=XX(20)*XX(10),
154                 XX(25)=XX(25)+XX(24); XX(20) THRU XX(25) TRAIN VARIABLES
155         ACT;
156         COLCT,XX(20),TIME FILLIN TRAN;
157         ACT;
158         COLCT,XX(23),TT FILL TRAN SAT;
159         ACT;
160         COLCT,XX(25),TT FILL TRAN SUN;
161         ACT;
162         TERM;
163
164
165
166         CREATE,,0,,1,1;              PRODUCTION DOWN TIME MODEL
167         ACT,UNFRM(5,55,3);           TIME BEFORE FIRST FAILURE
168 DOWN    ASSIGN,XX(7)=0;              PRODUCTION DOWN
169         ACT,UNFRM(2,8,3);            DOWN TIME
170         ASSIGN,XX(7)=UNFRM(5400,6600,3);PRODUCTION UP
171         ACT,UNFRM(15,45,3),,DOWN;    TIME BETWEEN FAILURES
172         END;
173 FIN;
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