A SIMULATION MODEL ON
THE OPTIMAL DESIGN OF
BELT CONVEYOR SYSTEMS

by
RICHARD L. SANFORD
and
CHARLES B. MANULA

An Investigation
Conducted Under the Auspices
of the

COAL RESEARCH BOARD
of the

COMMONWEALTH OF PENNSYLVANIA

Contract Number CR - 40

Special Research Report
Number SR - 47
March 5, 1965
STATEMENT OF TRANSMITTAL

Special Report SR-47 transmitted herewith has been prepared by the Coal Research Section of the Mineral Industries Experiment Station. Each of the Special Reports presents the results of a phase of one of the research projects supported by The Pennsylvania Coal Research Board or a technical discussion of related research. It is intended to present all of the important results of the Coal Board research in Special Reports, although some of the results may already have been presented in progress reports. The following is a list of Special Research Reports issued previously.

SR-1 The Crushing of Anthracite May 31, 1958
SR-2 Petrographic Composition and Sulfur Content of a Column of Pittsburgh Seam Coal August 1, 1958
SR-3 The Thermal Decrepitation of Anthracite September 15, 1958
SR-4 The Crushing of Anthracite with a Jaw Crusher November 1, 1958
SR-5 Reactions of a Bituminous Coal with Sulfuric Acid February 1, 1959
SR-6 Laboratory Studies on the Grindability of Anthracite and Other Coals April 1, 1959
SR-7 Coal Characteristics and Their Relationship to Combustion Techniques April 15, 1959
SR-8 The Crushing of Anthracite with an Impactor-Type Crusher April 25, 1959
SR-9  The Ignitibility of Bituminous Coal (A Resume of a Literature Survey)  April 25, 1959
SR-10  Effect of Gamma Radiation and Oxygen at Ambient Temperatures on the Subsequent Plasticity of Bituminous Coals  May 6, 1959
SR-11  Properties and Reactions Exhibited by Anthracite Lithotypes Under Thermal Stress  May 11, 1959
SR-12  Removal of Mineral Matter from Anthracite by Chlorination at High Temperatures  June 22, 1959
SR-14  The Effect of Nuclear Reactor Irradiation During Low Temperature Carbonization of Bituminous Coals  July 31, 1959
SR-15  Effect of Anthracite and Gamma Radiation at Ambient Temperatures on the Subsequent Plasticity of Bituminous Coals  August 5, 1959
SR-16  The Isothermal Kinetics of Volatile Matter Release from Anthracite  August 25, 1959
SR-17  The Combustion of Dust Clouds: A Survey of the Literature  November 30, 1959
SR-18  Changes in Coal Sulfur During Carbonization  June 15, 1960
SR-19  The Ignitibility of Bituminous Coal  August 1, 1960
<table>
<thead>
<tr>
<th>SR-20</th>
<th>The Radiation Chemistry of Coal in Various Atmospheres</th>
<th>September 12, 1960</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR-21</td>
<td>Reaction of Bituminous Coal with Concentrated Sulfuric Acid</td>
<td>October 1, 1960</td>
</tr>
<tr>
<td>SR-23</td>
<td>A Phenomenological Approach to the Batch Grinding of Coals</td>
<td>January 20, 1961</td>
</tr>
<tr>
<td>SR-24</td>
<td>The Unsteady State Diffusion of Gases from Anthracite at High Temperatures</td>
<td>January 21, 1961</td>
</tr>
<tr>
<td>SR-25</td>
<td>Some Advances in X-Ray Diffractometry and Their Application to the Study of Anthracites and Carbons</td>
<td>February 24, 1961</td>
</tr>
<tr>
<td>SR-26</td>
<td>The Filtration of Coal Solutions</td>
<td>March 17, 1961</td>
</tr>
<tr>
<td>SR-27</td>
<td>A Preliminary Investigation into the Application of Coal Petrography in the Blending of Anthracite and Bituminous Coals for the Production of Metallurgical Coke</td>
<td>May 1, 1961</td>
</tr>
<tr>
<td>SR-28</td>
<td>Preparation and Properties of Activated Carbons Prepared from Nitric Acid Treatment of Bituminous Coal</td>
<td>August 15, 1961</td>
</tr>
<tr>
<td>SR-29</td>
<td>The Reactions of Selected Bituminous Coals with Concentrated Sulfuric Acid</td>
<td>August 31, 1961</td>
</tr>
<tr>
<td>SR-31</td>
<td>Mineral Matter Removal from Anthracite by High Temperature Chlorination</td>
<td>March 26, 1962</td>
</tr>
<tr>
<td>Project Number</td>
<td>Description</td>
<td>Date</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>SR-32</td>
<td>The Effect of Crusher Type on the Liberation of Sulfur in Bituminous Coal</td>
<td>April 29, 1962</td>
</tr>
<tr>
<td>SR-33</td>
<td>Investigation of the Circular Concentrator - Flotation Circle System for Cleaning Fine Coal</td>
<td>September 10, 1962</td>
</tr>
<tr>
<td>SR-34</td>
<td>Reactions of Coal with Atomic Species</td>
<td>September 24, 1962</td>
</tr>
<tr>
<td>SR-36</td>
<td>A Study of the Burning Velocity of Laminar Coal Dust Flames</td>
<td>November 5, 1962</td>
</tr>
<tr>
<td>SR-37</td>
<td>Molecular Sieve Material From Anthracite</td>
<td>November 16, 1962</td>
</tr>
<tr>
<td>SR-38</td>
<td>Studies of Anthracite Coals at High Pressures and Temperatures</td>
<td>April 29, 1963</td>
</tr>
<tr>
<td>SR-39</td>
<td>Coal Flotation of Low-Grade Pennsylvania Anthracite Silts</td>
<td>May 13, 1963</td>
</tr>
<tr>
<td>SR-41</td>
<td>Some Aspects of the Chemistry of Sulfur in Relation to Its Presence in Coal</td>
<td>August 20, 1963</td>
</tr>
<tr>
<td>SR-42</td>
<td>The Unsteady State Diffusion of Gases from Coals</td>
<td>February 15, 1964</td>
</tr>
<tr>
<td>SR-43</td>
<td>The Effect of Concentration and Particle Size on the Burning Velocity of Laminar Coal Dust Flames</td>
<td>March 1, 1964</td>
</tr>
<tr>
<td>SR-44</td>
<td>The Electrokinetic Behavior of Anthracite Coals and Lithotypes</td>
<td>May 25, 1964</td>
</tr>
</tbody>
</table>
The Utilization of Coal Refuse For the Manufacture of Lightweight Aggregate

September 1, 1964

M. E. Bell, Director
M. I. Experiment Station
SUMMATION OF RESULTS

The selection of conveyor belts is primarily based on information regarding the expected flow rate of material to be handled. This parameter, however, is often obscure and difficult to estimate in operations experiencing intermittent production and parallel belt loading. As a result, an uncertain quantity is obtained upon which management must base decisions. The desirability for an objective means to describe material flow rates through a belt network, along with a technique for analyzing flow rate effects, seems necessary from the standpoint of economics.

This report is an account of an attempt to develop a simulation model describing the sequence of operations for a belt conveying system, from which decision variables can be retrieved. The model, which is based on a Monte Carlo sampling routine, allows management to pre-test many ideas on paper and compare these before final decisions are made. Model output is in the form of operational data to which representative costs are assigned.

Since the simulation model reported here involves a multitude of bookkeeping operations, a program is included for the IBM 7074 Computing System. Information from the computer was statistically tested against an actual operating system to determine its validity in predicting past operating experience. On the basis of this test it was surmised with reasonable certainty that this model, along with the appropriate data, is capable of simulating any belt conveying system for which operating characteristics are needed. More fundamentally, the basic model should provide theoretical concepts for further research and development concerning the simulation of a fully integrated mining system. Consequently, it is hoped that this report will provide an administrative understanding into the methods of simulation and the benefits to be derived thereof.
ACKNOWLEDGEMENTS

This report is based primarily on research conducted as part of the "Optimization of Mine Production Systems for Low Cost Mining," conducted by the Systems Engineering Unit, Department of Mining, College of Mineral Industries, The Pennsylvania State University. This work was done under contract with the Coal Research Board of The Pennsylvania Department of Mines and Mineral Industries, contract number CR - 40. The Systems Engineering Unit gratefully acknowledges the support of the Coal Research Board and gives a vote of thanks to C. R. B. for its farsighted support of research on decision problems for Pennsylvania's mining community. Special thanks should be given to the management of Barnes and Tucker Company for the use of their facilities and their assistance in making this study possible and, to the Coal Research Section of The Pennsylvania State University for the preparation of this manuscript.
# CONTENTS

| Acknowledgements                               | ii  |
| List of Tables                                 | v   |
| List of Figures                                | vi  |

## I. INTRODUCTION

| General                                         | 1   |
| Historical Background                          | 3   |
| Purpose and Scope                              | 5   |
| Statement of the Problem                       | 6   |
| Previous Related Studies                       | 9   |

## II. SYSTEMS SIMULATION

| Organizational Framework                       | 13  |
| 1. Selecting a Model                           | 13  |
| 2. Model Formulation                           | 15  |
| 3. Generating System Information              | 16  |
| 4. Testing the Model                           | 17  |
| Simulation in Practice                         | 18  |

## III. PROCEDURE OF THE INVESTIGATION

| Flow Model Constructed                        | 20  |
| Distribution of Production Data               | 20  |
| 1. Distribution of Shuttle Car Arrival Times  | 22  |
| 2. Distribution of Flow Rate                  | 22  |
| 3. Other Input Considerations                 | 23  |
| A. A Plan of the Belt System                  | 23  |
| B. Maximum Belt Capacities                    | 23  |
| C. Length of Production Shift                  | 25  |
| D. Minor Considerations                       | 25  |
| Model Output and Decision Criteria            | 27  |
| Development of the Computer Program           | 28  |
| Verification of the Model                     | 30  |

## IV. DISCUSSION AND RESULTS

| Free Running Belts                             | 34  |
| Limit Controlled Belts                         | 35  |
| Surge Controlled Belts                         | 35  |
| Results of the Alternatives                    | 36  |
## CONTENTS (Continued)

### V. SUMMARY AND CONCLUSIONS
- Other Contributions .................................. 38
- Future Research ...................................... 39
- Summary .............................................. 40

### A SELECTED BIBLIOGRAPHY ............................. 42

### APPENDIX A: Tables ................................. 46

### APPENDIX B: Fortran Listing for IBM 7074 Digital Computer Program ....................... 60

### APPENDIX C: Analysis of Alternate Computer Program ........................................ 70

### APPENDIX D: Part 1 - Monte Carlo Sampling Routine ........................................ 74
- Part 2 - An Example of Model Assumptions and Calculations ............................... 77
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cumulative Distribution of Shuttle Car Arrival Times for Five Miners</td>
<td>47</td>
</tr>
<tr>
<td>2</td>
<td>Maximum Belt Capacities</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>Results of Belts Running Free - 30 Inch Mother Belt</td>
<td>49</td>
</tr>
<tr>
<td>4</td>
<td>Results of Belts Running Free - 36 Inch Mother Belt</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>Results of Belts Running Free - 42 Inch Mother Belt</td>
<td>51</td>
</tr>
<tr>
<td>6</td>
<td>Results of Stopping Feeder Belts - 30 Inch Mother Belt</td>
<td>52</td>
</tr>
<tr>
<td>7</td>
<td>Results of Stopping Feeder Belts - 36 Inch Mother Belt</td>
<td>53</td>
</tr>
<tr>
<td>8</td>
<td>Results of Stopping Feeder Belts - 42 Inch Mother Belt</td>
<td>54</td>
</tr>
<tr>
<td>9</td>
<td>Results of Using Surge Control - 30 Inch Mother Belt</td>
<td>55</td>
</tr>
<tr>
<td>10</td>
<td>Results of Using Surge Control - 36 Inch Mother Belt</td>
<td>56</td>
</tr>
<tr>
<td>11</td>
<td>Results of Using Surge Control - 42 Inch Mother Belt</td>
<td>57</td>
</tr>
<tr>
<td>12</td>
<td>Summary of Results</td>
<td>58</td>
</tr>
<tr>
<td>13</td>
<td>Distribution of Load Buildup at the Mother Belt Head</td>
<td>59</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Minimum Cost Curve</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>System Flow Diagram</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>Schematic of Production Layout</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>Cross Section of Conveyor Belt Loading</td>
<td>26</td>
</tr>
<tr>
<td>5</td>
<td>Computer Program Flow Diagram</td>
<td>31</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

General

Materials handling represents a major economic problem to most mining enterprises, especially those concerned with the mass production of coal and the nonmetallic minerals. Since this group does not enjoy significant returns from the products mined, they are constantly faced with the improvement of existing production systems and the need to keep low profit materials away from high cost production faces. As a result, a rapid trend towards automated materials handling systems that require a minimum of supervision, attention and lag time is being experienced by these industries.

A natural solution for automation and the continuous handling of material is the use of conveyors. Since the above mineral industries represent a variety of products, continuous conveying systems under the general nomenclature of pneumatic, hydraulic and mechanical have been developed to handle this heterogeneity. The ones most commonly used in underground operations, however, are the mechanical types of which the belt conveyor finds widest application. This is especially true in bituminous coal operations contending with thin seam mining and complex haulage routes.

The use of belt conveyor systems in underground mining can generally be divided into two basic types. These are:

(1) Simple series network. This is a single belt or a series of belts which transport material to other handling units or to a
temporary storage location. The series system is widely applied to continuous handling of material between different mine levels and/or for underground to surface slope haulage.

(2) Parallel network. This system is usually characterized by loads discharging from various secondary belts to a primary gathering belt. This installation is most applicable to high production coal mines where many sections are mined concurrently, resulting in parallel loading on the main belt. Operations experiencing this type of belt loading are exemplified by some of the larger bituminous coal mines located in central Pennsylvania (Given 1963).

Since belt systems must be varied and tailored to fit individual mining needs, operations often contain complex combinations of the above networks which constitute high capital expenditures. Coupled with this is a long term investment for which any errors made in belt specifications at the onset could result in a pernicious effect to a mining enterprise. This growing cost and complexity has consequently resulted in the need for other than empirical methods for bringing the alternatives of belt selection into scope.

As a solution to complex decision problems, many operations have resorted to conceptual models supplemented by the electronic computer (Manula 1962). By these scientific and potentially better methods, management can closely predict the results of different alternatives before a final decision is made. A prime attribute for
using this approach is that these ideas are tested on paper without the cost experienced in changing the actual operation. These techniques have been widely applied in practice to other materials handling functions, however, their application to belt conveyor systems is not as yet significant.

**Historical Background**

The basic concepts used in modern belt conveyors are not recent innovations. Many of these features were conceived during the latter half of the nineteenth century by Lyster, an English engineer, who was working on the problem of continuously conveying bulk materials by endless belts. His prototype was constructed of two plies of canvas faced with rubber, which rode on spool shaped idlers. Further experimentation led to such improvements as: (1) smooth idlers to prevent wearing the belt edges, (2) the three way tripper, (3) the revolving cleaner brush, and (4) an attempt, apparently with little success, to devise two-roll troughing idlers.

During this period in the United States, Webster carried out independent research in moving grain with belt conveyors, and in the early 1890's, the inventor Edison built several cotton belt conveyors with skirt boards along the carrying run to reduce spillage.

Although these were significant contributions it still remained economically infeasible to use belt systems for most materials handling operations. However, through further contributions by Robbins in the 1890's, the most important of which were a three-roll
troughing idler with labyrinth grease seals and the stepped ply belt, interest was soon generated in belt conveying systems for limited industrial use (Hudson 1954). Significant underground applications of endless belt systems did not appear until 1924 when the Pennsylvania Coal and Coke Corporation installed face and mainline belts at Ehrefeld, Pennsylvania, and the H. C. Frick Coke Company started its Colonial Dock System. Following this trend the Harry Taylor Mine near Scranton, Pennsylvania, became the first all conveyor operation in 1933 (Given 1961).

These early underground installations exemplified the haulage economy and utility made possible by the belt conveyor, which soon found one of its greatest applications in the coal mining industry. During recent years innovations and modifications in conveyor systems have been largely dictated by coal mining needs. For example in 1955, Craggs and McCann at the number 17 mine of Peabody Coal Company developed the rope-frame conveyor, which has largely replaced the rigid frame conveyor. This type of installation is characterized by tensioned wire ropes supported at regular intervals by stands which may be supplemented by overhead roof bolt support. The troughing idlers are rope supported while the return idlers are attached to the supporting stands. Another significant example is the modern day belt carcass, which is usually composed of several plies of fabric or cord cushioned in rubber with a flame resistant Neoprene cover. The characteristics of such a belt are flexibility and light weight with sufficient strength to
transmit the necessary pull for carrying heavy loads; fire, rot and chemical resistance; and long wear (Jones 1962).

The highly competitive coal mining industry is constantly searching for methods to increase productivity and decrease costs. Apparent solutions to these problems are fully automated production systems utilizing endless belts. Undoubtedly then, research and development on belt conveyors for mining will continue to grow, especially in the areas of extensible and jointed belt systems.

Purpose and Scope

The selection of a suitable conveyor belt to satisfy haulage requirements is primarily based on the flow rate of production material, e.g., tons per hour. This rate is easily determined when a belt is loaded from a single source such as a shuttle car discharging onto a section belt. However, when a belt is loaded from several scattered sources, a situation common to primary gathering or mother belts, the problem of belt selection is compounded by a stochastic flow rate which causes unpredictable peak loads of unknown frequency and magnitude. The lack of information regarding these loading effects makes it rather difficult to economically balance belt utility with production. As a result, the purpose of this study is to supplement management's need to plan and forecast with a scientific tool for making intelligent decisions regarding the design, replacement, or revision of mother belt capacities in a complex belt network. This tool is a mathematical model based on a Monte
Carlo sampling routine which can be programed to simulate any given belt conveyor network. The model will not produce any one right answer, but rather present output in the form of operational data, from which different sets of alternatives can be compared.

Decisions that management must make are necessarily based on economics. The decision criteria for an efficient or optimum belt system are based on the costs assigned to the alternatives. These costs vary with each operation and can only be assigned as a result of intimate exposure to company records and operating procedures. At the risk of being unrealistic, therefore, it was decided not to include a specific cost study with the presentation of this model but rather to show where these costs might be incurred.

The validity of the proposed model need not be based on operating expenses; it is only necessary that the events portrayed by the model represent, in essence, some physical system. A large bituminous coal mine located in central Pennsylvania was chosen for the purpose of making such a test. This operation employs a free running, complex belt network to convey material from 10 production sections to an automatic, mine car loading station. The coal is extracted by a systematic development plan using shuttle cars directly behind a boring type continuous miner.

Statement of the Problem

The significant parameter to be identified in the selection of a conveyor system is the expected flow rate of production material.
However, as previously mentioned, the flow rate on a mother belt is not always apparent when production is very intermittent. Overlapping of material from various sections may result in peak material flow from 50 to 100 percent above average production (Raybestos-Manhattan 1958). Consequently, the unknown frequency and resulting flow rate of these overlapping loads cause difficulty in economically balancing belt utility with the production flow rate. To compensate for uncertainty, a conveyor system might be designed to handle peak production rates which implies the use of an oversized mother belt having only a portion of its potential capacity utilized. Conversely, a belt could be selected on the basis of average production, but frequent overloading would occur resulting in secondary materials handling due to spillage. An economic balance between these two extremes is needed for optimization, i.e., maximum utility with a minimum total cost. This idea is graphically portrayed in Figure 1.

In searching for an efficient system, the proposed model will investigate three basic alternatives. These are:

(1) Design the mother belt to handle a certain percentage of peak production, depending on the cost of secondary handling.

(2) Design for less than peak production, but include paddle or weight switches to sense mother belt overloads. The extent to which this might be used depends on the amount of section waiting which can be tolerated.
Figure 1

Minimum Cost Curve
Install ratio feeders at the shuttle car dump or at the section belt head. This essentially smooths the flow rate allowing the use of a smaller capacity mother belt.

Previous Related Studies

Most of the work relating to the development of mathematical models representing conveying systems is of a pioneering nature. A bibliography on the subject is rather limited with no publications available on endless belt systems. However, several representative studies conducted by non-mining groups on discrete conveyors will serve to show the potential of conceptual models in describing conveyor operations.

Kwo (1958) was among the first to apply a mathematical model to a conveyor system. This model, written in the context of an overhead-monorail system, was used to interrogate certain specific parameters common to this type of conveying system. Results from this investigation established the three following principles:

1. **Speed rule.** The speed of the conveyors must lie within a permissible range. The conveyor must move fast enough to handle the maximum loading rate, where the upper limit is the maximum unloading rate (in the case of discrete carriers).

2. **Capacity constraint.** The capacity must be great enough to handle incoming loads.

3. **Uniformity principle.** The conveyor must be loaded and
unloaded uniformly and have the material at the proper place when needed.

In an attempt to broaden Kwo's study, Morris (1962) developed a probability model for finding rotation times that satisfy the uniformity condition of the load carrier. This was accomplished for rotation times both less and greater than loading time.

Mayer (1960) developed a mathematical model for evaluating the effect of speed on the number of carriers in an overhead hook-trolley conveyor. His model is based on the binomial distribution, which is applicable here since a worker either will or will not offer an item to the carrier when it is within his reach. This results in a series of Bernoulli trials. Raphael (1962), in an unpublished study, broadens Mayer's model by considering additional assumptions regarding carrier span and capacity. Along these same theses Gonzalo (1962), in an unpublished study, attempts to generalize Mayer's approach to the hook-carrier problem. His model is based on the multinomial distribution and a Monte Carlo simulator will be used to test its validity.

Other classical examples of mathematical models dealing with hook type or discrete carriers include the following: (1) Ries, Dunlap and Schnieder (1963) developed a probability model for evaluating an individual work station. This model was written under the assumption that a conveyor is primarily used as a means of transporting materials rather than for storage, and (2) Disney (1963), in a new approach, applied waiting line methods to a two-station
conveyor and analyzed it as a multichannel queueing problem. The analysis is developed for an N item storage prior to entering station two, with the restriction of a single item storage prior to station one.

The preceding models are not directly applicable to endless belt systems unless rigid, generally unrealistic assumptions are applied. Further, an extensive literature search failed to uncover any published work that specifically refers to a mathematical model developed in this context. However, Nelson (1961), in an unpublished study, discusses the use of probability distributions for determining the optimum size of the mother belt in a complex belt network. He bases his model on the binominal distribution with the parameter, p, representing the probability of a belt being loaded. The binominal probabilities are used to construct graphs representing the amount of section belt idle time for the event in which the mother belt is fully loaded. The costs of these delays are analyzed in terms of lost production and are compared with various belt costs to arrive at an optimum combination. This model is one of the simpler methods for describing a belt system; however, a mathematical expression cannot be developed that will allow the consideration of all the desired system elements.
II. SYSTEMS SIMULATION

A mine manager is entrusted with the responsibility of safely and economically exploiting minerals. To obtain these desired objectives, he is continuously confronted with the problem of analyzing an interdependent system of men, machines and materials for decision-making purposes. In modern practice, however, the factors affecting these management systems have become so complex that their identification is often beyond the scope of intuition and experience. As a result, a more scientific and potentially better approach to decision-making problems has gained widespread acceptance in recent years. This new technique, commonly referred to as systems simulation, possesses the useful property of allowing experimentation on management systems in much the same way that an engineer might test a physical model in the laboratory. Systems simulation finds widespread application in stochastic systems which are too complex to be described by mathematical formulae (Malcolm 1958).

The practice of this science employs the formulation of a symbolic model which has, for a given purpose, the desired characteristics of the system being studied. This model mathematically represents the properties of a real physical system and, as such, provides a basis for experimentation on systems that cannot be designed in a physical form for normal laboratory use. The model can be formulated for different sets of alternatives, and these are compared
prior to final decisions. Simulation can be performed by an
electronic computer which enables the simulation of many months of
operation in a matter of minutes. Thus the expansion or compression
of the time scale is possible and a problem area can be analyzed
more critically. This property has led to the application of simulation
to understanding a system's behavior, searching for possible cost
reductions, pretesting ideas and personnel training (Saaty 1959).

Organizational Framework

Various and sometimes stringent procedures are employed in
the development of a systems simulation model. The degree of
refinement depends to a large extent on the nature of the system to
be analyzed and on the desired level of information retrieval.
However, there are certain basic organizational elements that must
be considered for any situation. These are necessary in identifying
the various factors of influence and in providing any essential clues
which lead to a workable model.

The background necessary for an understanding of the more
fundamental aspects of systems simulation is provided for in the
following general outline of procedure.

1. Selecting a Model. The first stage of development is
the selection of a model based on the type of representation which is
desired. For this phase, the system may be portrayed in several
ways depending on the intended use of the model. These are as follows:

(a) The physical model, which looks like what it
represents, and is exemplified by a map, a prototype of a machine or a plant production layout.

(b) The operational model, which is an analog of a system, and is represented by a logical sequencing of operations as they exist in reality.

(c) The analytical model, which represents reality only in essence, and its interactions can be stated by some mathematical expression (Alberts 1957).

The physical and operational models are not new innovations in systems analysis. They are widely used in experimental work both in industry and in the laboratory, and until recently were the only tools available for portraying ideas and for limited systems information. However, in recent years, especially since the advent of electronic computers, the analytical model has found its way into most segments of modern industry. These models, as opposed to the physical and operational types, are potentially more dynamic, i.e., the operational schemes can be readily simulated for a multitude of situations.

Since the analytical model is a relatively new concept in systems analysis, its underlying assumptions and genesis are probably the least understood. Consequently, the remainder of this section is primarily devoted to the organizational structure of this model type. This is also appropriate, since this thesis is written in the context of an analytical model.
2. **Model Formulation.** The second stage of development, concerning the use of an analytical model, is to construct a flow diagram. This diagram is a visual aid for intuitively establishing a set of strategical considerations which lead to a workable analytical formulation. Here, the division of the system into its major elements is considered. This gives the sequence and manner in which unit operations are performed and provides insight into the type of data needed to indicate how these unit functions are interrelated. Consequently, the interactions of system components are identified, as are the many factors which do not contribute significantly to system objectives.

Once the system components are isolated and can be visualized, a framework of reference for acquiring and analyzing the data which describe the system is defined. These data are generally obtained through time studies and require statistical methods for analysis. These methods are especially valuable for determining required sample sizes, elimination of extreme values and establishing variance ratios. Some examples of special statistical techniques which are employed in data preparation are: (1) analysis of variance, which is used to obtain information as to the factors which contribute to some observed variation, and (2) correlation and regression, which provide information for prediction and control (Crow, Davis and Maxfield 1960).

The need for exact methods of data analysis is quite apparent when the quantity of data which must be gathered is considered.
Collecting data is both time consuming and costly. Consequently, the model must be capable of utilizing the data significantly, otherwise it has no value.

3. Generating System Information. The third stage of procedure is concerned with the manipulation of input data in a manner that simulates the operational scheme of events described in the flow model. Many numerical and probabilistic techniques are available for generating this system information (Kaufmann 1963); however, situations arise where the mode of attack is very limited because of special system characteristics. For example, some stochastic systems cannot easily be handled by probability formulae or analytical expressions, in which case the Monte Carlo technique is useful (Sasieni, Yaspan and Friedman 1959). Since this study investigates such a system, Part 1, Appendix D, provides the background for understanding Monte Carlo Sampling.

Monte Carlo is essentially a random sampling routine commonly referred to as exploiting the laws of chance. It involves a multitude of diversified bookkeeping operations that necessitate the use of Gantt charts or, in more complex problems, high speed digital computers. These computational aids accurately record the desired information as the simulation progresses through specified time cycles.

The Monte Carlo simulation has the ability to be interrogated point by point, allowing compression or expansion of real time. This
property has proved especially valuable in allowing management
to critically analyze a particular problem area. Another prime
attribute for using the Monte Carlo method is that the simulation
need not rely on average values. This attribute has proven
especially valuable for equipment reliability studies where the peak
operating hours, storage requirements and waiting line lengths have
to be predicted under prescribed limits of confidence. In summary,
the information derived from a Monte Carlo simulation depends
largely on how well the output has been designed, since it does not
possess the natural limitations imposed on, for example, linear
programming or queueing models.

4. Testing the Model. The final stage of development in
systems simulation is probably the most important, yet one of the
most frequently overlooked. This phase of analysis is provided for
the purpose of testing the model against a real situation. The testing
process is concerned with the ability of the simulator to predict
past experience and involves the comparison of real operational
data to simulated operational data. If the simulator possesses these
characteristics, it is appropriate to assume that the model is
capable of predicting future operating policies, and more significant-
ly that it can make predictions about similar physical systems
which have not as yet been built and whose behavior patterns are
unknown.

For simplicity it is often desirable to test the model against
a less complex situation than the one being studied. In this way
the output from the model is more easily comprehended and its utility more apparent. Whatever method of testing is chosen, it is only logical that some comparison must be made against the model's physical counterpart to demonstrate its usefulness in practice.

Simulation in Practice

Since its advent during World War II, at which time it was used by the military as a war gaming technique, systems simulation employing Monte Carlo methods has proved itself in many branches of industrial practice. Although the mining industry has been rather cautious in promoting the applications of this technique to management systems, a rapid change is developing. Some recent examples showing the application of simulation to mining problems include the following: (1) Falkie (1961) simulated the haulage system in a mechanized coal mine to determine the optimum ratio of main line cars per trip to section service cars. He was further able to predict trip composition, storage space, surge, optimal car movement and car storages; (2) Manula (1963) used Monte Carlo to demonstrate and explore changes in future operating policies for an existing track haulage system in an operating bituminous coal mine. He specifically investigated fixed car storage and attempted to minimize system wait time by adding more cars as production increased; (3) Rist (1962) used simulation to predict optimal decisions concerning the allocation
of future mine production. His method of attack was to simulate the productive capacity of an adit and crusher on a specific mine level; (4) Achttien and Stine (1964) supplemented Rist's study by finding the maximum rate of production that could be sustained with a single adit under present operating conditions. These men further investigated the effect of adding a second adit and what reasonable modifications in the single adit system would permit a production increase.
III. PROCEDURE OF THE INVESTIGATION

A simulation model written specifically to test the following alternatives regarding the selection of belt conveyors is provided in this section:

(1) Use a mother belt which will carry a certain percentage of peak production.

(2) Use sensing switches to prevent overloading of the mother belt during peak flow rates.

(3) Use ratio feeders to smooth peak production flow.

Using the procedures and physical system previously outlined, the model is designed and constructed in the following manner.

Flow Model Constructed

A typical section flow model illustrated in Figure 2 describes the sequence of operations for this particular system. The factors that significantly influence belt selection are identified as production rates and belt capacities. The data necessary to describe production phenomena are defined by probability distributions for shuttle car arrival times and material flow rates. Information regarding belt capacities is derived from estimates based on manufacturers' specifications coupled with the bulk density and cross sectional area of the material.

Distribution of Production Data

The primary data for production consist of distributions and
System Flow Diagram
expected values of the estimated parameters. These are briefly described as follows:

1. **Distribution of Shuttle Car Arrival Times.** Since the production units for each section were not homogeneous, it was necessary to obtain separate distributions for describing arrival rates. These were available for five sections (Manula 1963) and are shown in Table 1, Appendix A. The remaining five distributions were assigned from the above according to a systematic development plan.

2. **Distribution of Flow Rate.** From random observations, the distributions of load length in time units along the feeder belts were assumed to be normal with the following statistics:

   \[
   \bar{X} = 0.50 \text{ minutes} \\
   s^2 = 0.15 \text{ minutes}
   \]

The factors affecting the variance \(s^2\) were expressed in terms of fluctuating shuttle car loads and discharge times. Since the degree of influence imposed by these factors, varying singly or in combination, could not easily be determined, an estimate was made on the expected shuttle car load. This estimate was derived from production records and other information furnished by company personnel. The assignment of these expected shuttle car loads is as follows:

- Development sections - 2.75 tons per shuttle car
- Production sections - 3.00 tons per shuttle car
Although allowances were made to generate discharge rates from a normal distribution, it was deemed realistic to consider only the expected value of load length combined with these expected load weights to predict flow rates on the feeder belts.

3. Other Input Considerations. Along with the production and servicing distributions, other pertinent variables regarding an operating belt system are introduced to complement model input. These are identified and defined as follows:

A. A Plan of the Belt System. This involves the number and location of the feeder belts relative to the mother belt. Figure 3 is a symbolic model showing the relative positions of the production sections as they were assigned.

B. Maximum Belt Capacities. Some idea on speed and size ranges for the proposed belt system is required to define the problem boundaries. Table 2, Appendix A, shows the belt speeds and sizes, along with the corresponding maximum allowable loads which were used in this study.

Numerous manufacturer's handbooks are available that list the recommended capacities for different belt conveyor sizes (Hewitt-Robins, anon). These figures were found to be more conservative than necessary for the purpose of this study and were therefore not used. Since the bulk density, loading and slumping qualities of coal are highly variable even on a daily basis in an individual operation, the capacities given in Table 2, Appendix A, were derived from expected cross-sectional areas of material
Schematic of Production Layout

Figure 3
on the belt. These were idealized from experience and consistency with the operation at which the model was tested and are illustrated in Figure 4. It is felt that, even though these capacities might be still somewhat conservative, advantage is taken of the better loading qualities of this particular type coal, and the capacities are more consistent with practical experience. The general use of this model would certainly require a study of the coal characteristics for an individual operation.

C. Length of Production Shift. A common measure or standard evaluation is necessary for model output. Since a production shift is a common means of evaluating operational data in practice, it was chosen as the criterion for information retrieval from this model. For the purpose of this investigation an expected value of 6.5 hours was used rather than a distribution of shift times. Although the distribution is more realistic, it does not significantly contribute to the sensitivity of the model.

D. Minor Considerations. Other distributions were considered; however, their contribution to model sensitivity was not relevant to this study. These were:

1. The distribution of feeder belt lengths as production and development faces advance.
2. The distribution of production shifts for each section.
3. The distribution of production changes dictated by a
Cross Section of Conveyor Belt Loading

Figure 4

Cross Section of Conveyor Belt Loading
variable demand. The system under study was assumed to be in a static condition.

Model Output and Decision Criteria

In order to evaluate a given input under consideration, the data identifying the sequence of operations are consulted in a random fashion. This process, repeated over and over on a per shift basis, simulates the operations of the belt system and permits accruing such total output data as average belt utilization, waiting time and belt overloading. This, in effect, is the simulated experience conducted by the model.

Optimization of belt conveyor systems is achieved by combining the cost of conveyor belts with the cost of system effects produced by this belt. In the case of free running belts, the system effects are in terms of lost production due to overloaded conditions. If certain belts are stopped in the system to prevent overloading, the effects are defined in terms of waiting time for these sections coupled with possible increased power requirements for accelerating loaded belts. Finally, if surge controls are imposed on the system, the effects of these added channels are the significant factors.

Deriving the costs incurred from these system effects is a difficult task, especially for the waiting time and spillage. The waiting time is linked to idle equipment and lost production, while spillage is evaluated in terms of secondary handling charges. These
are internal costs and can only be evaluated by intimate exposure to operational data. Equipment costs, on the other hand, can easily be obtained from the manufacturer and assigned accordingly. However, as specified previously, there were no operational costs available for this investigation. Only the decision criteria based on the three specified alternatives are considered here in order to apply the idea of optimization for demonstrating how such costs would be incurred in an operating system.

Development of the Computer Program

The need for a computer was apparent when the large volume of calculations and bookkeeping procedures required by this simulation model became evident. Also, the complexity of many of these operations is such that their execution without the aid of a computer would be extremely time consuming if not feasible. The computer program was therefore written for The Pennsylvania State University Fortran Compiler Version of the IBM 7074 digital computer, which would accurately perform the sequence of operations necessary for the simulation of a belt conveyor system.

The central procedure for programing a belt system involves a technique for sampling frequency distributions which describe shuttle car arrival times at the feeder belts. This technique is available in various references and involves generating a random number on a distribution function and returning with a value for the random variable (Churchman, Ackoff and Arnoff, 1957).
This procedure is then repeatedly used to determine the arrival pattern of a shuttle car. A numerical analysis must then be employed to trace this shuttle car load along the carrying run of the belt system. During the course of flow the load may encounter many situations that are significant to the analysis and must be evaluated.

An initial attempt was made in following the load of coal along the conveyor belts using an event by event analysis, however, the complexity of this approach became prohibitive. Another type of numerical analysis was developed which divided each belt's length into discrete time units. This procedure performed the computations satisfactorily, but the required computer time made it impractical for a 10 feeder belt system. Although this program is not used for this study, it is felt that its development might be significant for other applications and a brief description is given in Appendix C.

It became evident at this point that a somewhat different approach to this problem was necessary, which ultimately led to the development of the program used in this study. This program differs somewhat from the others since no attempt is made to analyze the loads as they pass through the system. Instead of interrogating a load during the course of flow, the computer is instructed to wait until the load passes through the system. The path of this load is then retraced and the effects on the system
are analyzed. This procedure eliminated the need to make complex decisions when new system elements are encountered. The computer performs the required simulation in a fraction of the time needed for the previous programs; consequently it is considered a satisfactory computational aid for this simulation study. These ideas may be made clearer by applying them to a hypothetical problem using a hand computational routine illustrated in Part 2, Appendix D. A flow diagram for this program is shown in Figure 5.

Verification of the Model

This model was verified by testing it against an operating bituminous coal mine located in central Pennsylvania. The feeder belts in this operation are not limit controlled, i.e., if the mother belt is overloaded, secondary handling is required. The quantity of this spilled material was estimated by company personnel to be negligible, or in the order of 0.1 to 0.5 tons per shift. Since this was only an estimate based on experience, no statistical test was performed on these figures. The comparison between these tonnages and those produced by the model, however, appeared to agree within a small enough tolerance to accept the model output of 0.51 tons as representative.

A further comparison between the model and the operating system was made on total shift production. Actual production statistics showed a mean value \( \bar{X}_a \) of 2563 tons and standard deviation \( S_a \) of 137 tons based on a 50 shift random sample \( N_a \), using 10 production units. The simulator, with equal sample size
Computer Program Flow Diagram
(N_m), gave a mean production \((\bar{X}_m)\) of 2541 tons and a standard deviation \((S_m)\) of 116 tons. To determine if these two samples are derived from the same parent population, the hypothesis:

\[
H: \sigma_m = \sigma_a
\]

was tested to see if the difference between the standard deviations can be attributed either to chance or sampling. Using the F test with statistics \(S_a\) as an estimate of \(\sigma_a\) and \(S_m\) as an estimate of \(\sigma_m\), the calculated variance ratio is as follows:

\[
F_{\text{statistic}} = \frac{(S_a^2)}{(S_m^2)} = \frac{(18695)}{(13320)} = 1.40
\]

Using a level of significance \((\alpha)\) of 5 percent and a two-tailed test, the F statistic should lie between:

\[
F_{\frac{1}{2}} < F_{(N_a - 1, N_m - 1)} < F_{1 - \frac{1}{2}} \text{ for } (N_a - 1, N_m - 1)
\]

\[
0.55 < F_{\text{statistic}} < 1.84
\]

Since 1.40 lies within these limits it can be assumed with statistical reliability that the standard deviations are equal.

The acceptance of the simulated production figures was further validated by testing the mean parameters:

\[
H: \mu_a = \mu_m
\]

with the t distribution to show that the sample statistics, \(\bar{X}_a\) and \(\bar{X}_m\) came from two populations having means \(\mu_a = \mu_m\). The variance from each population is unknown, however, from the previous variance ratio test it is justified to use the pooled mean-
square estimate \((S_p^2)\) for the population estimator \((\sigma^2)\). \(S_p^2\) is calculated as follows:

\[
S_p^2 = \frac{[(N_a-1)S_a^2 + (N_m-1)S_m^2]}{(N_a + N_m - 2)}
\]

\[
= \frac{[(50-1)18695 + (50-1)13320]}{(50+50-2)}
\]

\[
= 16008
\]

The value of the t statistic using the estimator \(S_p\) is calculated as follows:

\[
t = \frac{X_a - X_m}{S_p \sqrt{(1/N_a) - (1/N_m)}}
\]

\[
= \frac{(2563-2541)}{127 \sqrt{(1/50) - (1/50)}}
\]

\[
= \pm .47
\]

From tabulated values of t for \(\alpha = .05\) and a two-tailed test, the null hypothesis is accepted if

\[-1.96 \leq t \text{ statistic} \leq +1.96\]

Since the t statistic is within these limits, it is probably true that the sample means are derived from a common parent population (Hald 1962). Consequently it can be concluded from the results of these two tests that the model is simulating the sequence of operations with reasonable certainty.
IV. DISCUSSION AND RESULTS

The sequence of operations for a belt system was programmed into the memory of an electronic computer along with the appropriate data to run a 50 shift simulation for testing the three alternatives, using 30, 36, and 42 inch belts for each. Production for the system was fixed for each simulation run, resulting in a common basis for comparing operational schemes. The simulation analysis for this proposed mode of attack is presented in detail in the following discussion of results.

Free Running Belts

The feeder belts were allowed to discharge their full load to the mother belt, even when an overloaded condition would result. The three sizes of mother belts were tested using the capacities given in Table 2, Appendix A. The results from this simulation run are listed in Tables 3-5, Appendix A, which show, as expected, a decreasing spillage rate as the mother belt size is increased.

It is common knowledge that the initial investment, including installation and maintenance, will increase as belt width and/or speed increase and, conversely, the production differential costs resulting from secondary materials handling will increase as the belt size decreases. However, as the size of the mother belt becomes smaller, an extreme will be reached where lost production becomes prohibitive to an efficient operation of the
system. These factors result in an economic balance problem which involves the comparison of these costs in order to reach an optimum operating condition for a specified situation.

Limit Controlled Belts

Using the production parameters from the preceding run, alternative 2 was tested for the various belt sizes. These results are listed in Tables 6-8, Appendix A, and demonstrate increased section wait time as belt size decreases.

A smaller mother belt can be used to handle the same production using a limit controlled system. However, an extreme will be reached where the section wait time becomes prohibitive, as the mother belt size decreases. The magnitude of this wait time, as shown in Table 6, is quite significant with the 30 inch belt.

The use of limit switches to control overloading is common in coal mining practice (Goodyear 1953). In operations where the stopped belt may receive material from other belts, sequencing must be employed to prevent material from discharging to the nonoperating belt. This situation may present an additional curtailment to production output. The efficiency of limit switches for overload prevention largely depends on the development plan in use at the particular operation.

Surge Controlled Belts

Installation of surge units with ratio feeders at either the head or tail end of section belts would produce the same production
smoothing effect as the shuttle car discharging at a slower rate. Such installations would smooth overall flow rates, thus allowing the use of a smaller capacity mother belt.

The simulated results of installing surge units on the three feeder belts nearest to the mother belt head are shown in Tables 9-11, Appendix A. These results demonstrate an increase in belt utility and the elimination of system wait time. However, the installation of these surge units would be quite costly and rock excavation may be required in low coal seams. Depending on the operation, this installation could result in a smaller investment than the use of the other two alternatives.

Results of the Alternatives

Table 12, Appendix A, is a summary of the results produced by the simulation model for the three alternatives. This summary shows the average lost production and wait time experienced from using the 30, 36, and 42 inch belts. The operating system around which this model was designed uses a 42 inch mother belt with very satisfactory results, according to company personnel. The 42 inch belt, however, is not the only solution to the haulage problem at this operation, and Table 12 illustrates changes imposed on the system by using 30 and 36 inch mother belts. The use of these smaller belts would be feasible if the total cost for these belt systems is found to be less than for the present installation. These costs can be directly assigned to the values given in Table 12,
as discussed previously.

Various combinations of these alternatives and other belt sizes may also be tested until the investigator is satisfied that he has encompassed the least cost combination to optimize an existing system. In addition, one might be concerned with future expansion or need to make decisions concerning a belt system that has not as yet been built and whose behavior patterns need to be known.
V. SUMMARY AND CONCLUSIONS

Other Contributions

A simulation model is usually written for a single purpose or goal. However, in most cases other ideas become readily apparent, i.e., one usually obtains more than he has bargained for. For this particular situation the development of the model revealed two additional concepts which are considered to be significant contributions to decision problems regarding conveyor systems.

It is felt, therefore, that a few pertinent remarks regarding these concepts should be given:

(1) A discrete simulation model was developed at the outset of this investigation, for which a computer program (Appendix C) was written and tested. This model performed the simulation satisfactorily except for the excessive computer time which was required for a parallel belt system. However, this model might find application in some similar study such as would be expected in the analysis of discrete carrier conveyors.

(2) The distribution of load buildup at the mother belt head was derived for the purpose of designing the capacity of a surge unit which is commonly installed at the belt terminus for loading other production units. The lack of knowledge concerning the size and frequency of a fluctuating load discharge to this facility results in a
serious design problem. The formulation for generating the distribution of incoming loads is therefore included in the model, with an example for the system which was studied shown in Table 13, Appendix A.

Future Research

Following the development of this model, certain areas which require further research were noted. These are briefly described as follows:

(1) An increase in program efficiency would allow more shifts to be simulated at a lower cost. This might be accomplished either by making reasonable assumptions which further simplify the model, or by applying refined programming techniques.

(2) The derivation of a distribution which incorporates the combined effect of the variance in both the load length and flow rate along the feeder belts might be desirable. This would increase model sensitivity since the present simulation uses only average values.

(3) The derivation and construction of nomographs or tables to convey the results of this simulator is needed to eliminate a simulation run every time an alternative is to be evaluated.

(4) A study on the bulk density and belt loading characteristics of various coals or other material types is required. This
would aid in eliminating the high safety factor now used in belt selection and would also add to the versatility of the model presented in this investigation.

Summary

This investigation is an account of an attempt to develop a simulation model describing a belt system as it was found to exist in an underground bituminous coal mine. The model, using the principles of Monte Carlo, has the capability of simulating any conveyor belt system for which appropriate data can be obtained. The application might encompass one or a combination of the following:

(1) The determination of a set of decision rules concerning present and future operating policies for an existing conveyor system.

(2) A system that is not yet in production and for which belt conveyors need to be selected.

Any changes can be incorporated into the model and tested prior to the installation in the real system. The data for the system that is not yet in production is obtained from similar systems presently in operation.

The output from the model is presented in a form to which representative costs can be assigned for choosing optimum alternatives. The prime attribute of the model is that it provides management with a presentation of the results of his decisions.
before they actually have to be committed to the real system. These factors eliminate costly trial and error methods and could result in a substantial cost savings for a mining enterprise.

The basic concepts of this model should provide the framework for further research and development regarding the use of simulation techniques for analyzing belt conveying systems. Management's need to rely entirely on manufacturers' estimates and recommendations regarding optimal belt selection can be partially eliminated by using this scientific method. Since simulation has been applied to related haulage problems, it is felt that its application to belt selection should supplement the concepts which are necessary for the simulation of a fully integrated mining system.
BIBLIOGRAPHY

SELECTED

A
A SELECTED BIBLIOGRAPHY


12. ______________, 1961, 50 years ... and ahead in face supporting services, Coal Age, v 66, n 10, pp 175.
13. 1963, Longest coal belt system, television
control, Coal Age, v 68, n 7, pp 78-83.

Conveyors, M. S. Thesis Proposal, Department of
Industrial Engineering, The Pennsylvania State
University.

15. Goodyear Tire and Rubber Company, 1953, Handbook of
Belting - Conveyor and Elevator, Akron, Ohio.

Applications, John Wiley and Sons, Inc., New York,
pp 394-398.

York.

18. Hewitt-Robins, anon., Conveyor Belt Engineering, Bull. 175,
Stamford, Conn.


20. Jones, D. C., 1962, Belt conveyor installation costs,
Mechanization, v 26, n 6, pp 37-46.


22. Koenigsberg, E., 1958, Cyclic queues, Operations Research
Quarterly, v 9, n 1, pp 22-35.

23. Kwo, T. T., 1958, A theory of conveyors, Management Science,
v 5, n 1, pp 51-71.


Business, v 46, n 2, pp 64-68.

26. Manula, C. B., Operations research - a new tool for mining,

27. 1963, Mathematical Simulation of a Mine
Transportation Problem, M. S. Thesis, The Pennsylvania
State University.


<table>
<thead>
<tr>
<th>Miner</th>
<th>Mean</th>
<th>1.005</th>
<th>3.055</th>
<th>5.105</th>
<th>7.155</th>
<th>9.205</th>
<th>11.255</th>
<th>13.305</th>
<th>15.355</th>
<th>17.405</th>
<th>60.455</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.11</td>
<td>0.000</td>
<td>0.115</td>
<td>0.602</td>
<td>0.791</td>
<td>0.885</td>
<td>0.937</td>
<td>0.955</td>
<td>0.967</td>
<td>0.974</td>
<td>1.000</td>
</tr>
<tr>
<td>2</td>
<td>4.26</td>
<td>0.000</td>
<td>0.548</td>
<td>0.856</td>
<td>0.908</td>
<td>0.935</td>
<td>0.956</td>
<td>0.962</td>
<td>0.969</td>
<td>0.979</td>
<td>1.000</td>
</tr>
<tr>
<td>3</td>
<td>3.53</td>
<td>0.000</td>
<td>0.715</td>
<td>0.843</td>
<td>0.912</td>
<td>0.945</td>
<td>0.964</td>
<td>0.978</td>
<td>0.989</td>
<td>0.993</td>
<td>1.000</td>
</tr>
<tr>
<td>4</td>
<td>3.96</td>
<td>0.000</td>
<td>0.669</td>
<td>0.842</td>
<td>0.896</td>
<td>0.932</td>
<td>0.954</td>
<td>0.972</td>
<td>0.972</td>
<td>0.986</td>
<td>1.000</td>
</tr>
<tr>
<td>5</td>
<td>5.78</td>
<td>0.000</td>
<td>1.458</td>
<td>0.651</td>
<td>0.831</td>
<td>0.905</td>
<td>0.943</td>
<td>0.955</td>
<td>0.969</td>
<td>0.979</td>
<td>1.000</td>
</tr>
<tr>
<td>Belt Width (inches)</td>
<td>Assigned Speed (ft. /min.)</td>
<td>Bulk Density of Load (lb. /ft.³)</td>
<td>Cross Sectional Area of Load (ft.²)</td>
<td>Maximum Allowable Load (tons/hr.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------</td>
<td>---------------------------------</td>
<td>-----------------------------------</td>
<td>----------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeders</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>400</td>
<td>50</td>
<td>1.1</td>
<td>570</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>400</td>
<td>50</td>
<td>1.5</td>
<td>930</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mother</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>550</td>
<td>50</td>
<td>1.1</td>
<td>900</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>550</td>
<td>50</td>
<td>1.5</td>
<td>1300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>550</td>
<td>50</td>
<td>2.3</td>
<td>1900</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3

Results of Belts Running Free - 30 Inch Mother Belt
50 Shift Simulation

<table>
<thead>
<tr>
<th>Feeder Number</th>
<th>Total Tons Produced</th>
<th>Tons Contributed to Overload Main</th>
<th>Number of Loads Carried</th>
<th>Belt Wait Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13755.00</td>
<td>2155.06</td>
<td>4585</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>15252.00</td>
<td>1836.54</td>
<td>5084</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>16275.00</td>
<td>1390.17</td>
<td>5425</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>8283.00</td>
<td>529.61</td>
<td>3012</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>13011.00</td>
<td>608.62</td>
<td>4337</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>14913.00</td>
<td>344.17</td>
<td>4971</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>8423.25</td>
<td>113.59</td>
<td>3063</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>14418.00</td>
<td>51.25</td>
<td>4806</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>14160.00</td>
<td>0.00</td>
<td>4720</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>8244.50</td>
<td>0.00</td>
<td>2998</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total Tons Produced = 126734.75

Average Tons Per Shift = 2534.70

Variance in Shift Production = 9035.92

Total Tons Lost Due to Exceeding Allowable Load on Main = 7029.01

Average Tons Per Shift = 140.58

Variance in Tons Lost Per Shift = 405.84
Table 4

Results of Belts Running Free - 36 Inch Mother Belt
50 Shift Simulation

<table>
<thead>
<tr>
<th>Feeder Number</th>
<th>Total Tons Produced</th>
<th>Tons Contributed to Overload Main</th>
<th>Number of Loads Carried</th>
<th>Belt Wait Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13635.00</td>
<td>403.83</td>
<td>4545</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>14580.00</td>
<td>286.39</td>
<td>4860</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>16143.00</td>
<td>191.89</td>
<td>5381</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>8833.00</td>
<td>59.31</td>
<td>3212</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>13266.00</td>
<td>52.18</td>
<td>4422</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>14472.00</td>
<td>13.85</td>
<td>4824</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>8431.50</td>
<td>1.79</td>
<td>3066</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>14406.00</td>
<td>0.00</td>
<td>4802</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>14460.00</td>
<td>0.00</td>
<td>4820</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>8365.50</td>
<td>0.00</td>
<td>3042</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total Tons Produced = 126592.00

Average Tons Per Shift = 2531.84

Variance in Shift Production = 10098.37

Total Tons Lost Due to Exceeding Allowable Load on Main = 1009.24

Average Tons Per Shift = 20.18

Variance in Tons Lost Per Shift = 35.47
Table 5

Results of Belts Running Free - 42 Inch Mother Belt
50 Shift Simulation

<table>
<thead>
<tr>
<th>Feeder Number</th>
<th>Total Tons Produced</th>
<th>Tons Contributed to Overload Main</th>
<th>Number of Loads Carried</th>
<th>Belt Wait Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13635.00</td>
<td>16.02</td>
<td>4545</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>14580.00</td>
<td>6.98</td>
<td>4860</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>16143.00</td>
<td>2.50</td>
<td>5381</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>8833.00</td>
<td>0.00</td>
<td>3212</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>13266.00</td>
<td>0.00</td>
<td>4422</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>14472.00</td>
<td>0.00</td>
<td>4824</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>8431.50</td>
<td>0.00</td>
<td>3066</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>14406.00</td>
<td>0.00</td>
<td>4802</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>14460.00</td>
<td>0.00</td>
<td>4820</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>8365.50</td>
<td>0.00</td>
<td>3042</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total Tons Produced = 126592.00
Average Tons Per Shift = 2531.84
Variance in Shift Production = 10098.37

Total Tons Lost Due to Exceeding Allowable Load on Main = 25.51
Average Tons Per Shift = 0.51
Variance in Tons Lost Per Shift = 0.58
Table 6

Results of Stopping Feeder Belts - 30 Inch Mother Belt
50 Shift Simulation

<table>
<thead>
<tr>
<th>Feeder Number</th>
<th>Total Tons Produced</th>
<th>Tons Contributed to Overload Main</th>
<th>Number of Loads Carried</th>
<th>Belt Wait Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12597.00</td>
<td>0.00</td>
<td>4199</td>
<td>1301.46</td>
</tr>
<tr>
<td>2</td>
<td>14427.00</td>
<td>0.00</td>
<td>4809</td>
<td>1051.43</td>
</tr>
<tr>
<td>3</td>
<td>15375.00</td>
<td>0.00</td>
<td>5125</td>
<td>741.91</td>
</tr>
<tr>
<td>4</td>
<td>8494.75</td>
<td>0.00</td>
<td>3089</td>
<td>335.33</td>
</tr>
<tr>
<td>5</td>
<td>13071.00</td>
<td>0.00</td>
<td>4357</td>
<td>313.12</td>
</tr>
<tr>
<td>6</td>
<td>14637.00</td>
<td>0.00</td>
<td>4879</td>
<td>195.80</td>
</tr>
<tr>
<td>7</td>
<td>8536.00</td>
<td>0.00</td>
<td>3104</td>
<td>74.55</td>
</tr>
<tr>
<td>8</td>
<td>14523.00</td>
<td>0.00</td>
<td>4841</td>
<td>25.98</td>
</tr>
<tr>
<td>9</td>
<td>14106.00</td>
<td>0.00</td>
<td>4702</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>8316.00</td>
<td>0.00</td>
<td>3024</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total Tons Produced = 124082.75

Average Tons Per Shift = 2481.66

Variance in Shift Production = 11512.24

Total Tons Lost Due to Exceeding Allowable Load on Main = 0.00

Average Tons Per Shift = 0.00

Variance in Tons Lost Per Shift = 0.00
## Table 7

Results of Stopping Feeder Belts - 36 Inch Mother Belt
50 Shift Simulation

<table>
<thead>
<tr>
<th>Feeder Number</th>
<th>Total Tons Produced</th>
<th>Tons Contributed to Overload Main</th>
<th>Number of Loads Carried</th>
<th>Belt Wait Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13383.00</td>
<td>0.00</td>
<td>4461</td>
<td>232.40</td>
</tr>
<tr>
<td>2</td>
<td>15141.00</td>
<td>0.00</td>
<td>5047</td>
<td>169.31</td>
</tr>
<tr>
<td>3</td>
<td>15816.00</td>
<td>0.00</td>
<td>5272</td>
<td>95.54</td>
</tr>
<tr>
<td>4</td>
<td>8569.00</td>
<td>0.00</td>
<td>3116</td>
<td>37.38</td>
</tr>
<tr>
<td>5</td>
<td>13158.00</td>
<td>0.00</td>
<td>4386</td>
<td>24.52</td>
</tr>
<tr>
<td>6</td>
<td>14460.00</td>
<td>0.00</td>
<td>4820</td>
<td>9.08</td>
</tr>
<tr>
<td>7</td>
<td>8288.50</td>
<td>0.00</td>
<td>3014</td>
<td>1.26</td>
</tr>
<tr>
<td>8</td>
<td>14226.00</td>
<td>0.00</td>
<td>4742</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>14706.00</td>
<td>0.00</td>
<td>4902</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>8250.00</td>
<td>0.00</td>
<td>3000</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total Tons Produced = 125997.50

Average Tons Per Shift = 2519.95

Variance in Shift Production = 12254.29

Total Tons Lost Due to Exceeding Allowable Load on Main = 0.00

Average Tons Per Shift = 0.00

Variance in Tons Lost Per Shift = 0.00
Table 8

Results of Stopping Feeder Belts - 42 Inch Mother Belt
50 Shift Simulation

<table>
<thead>
<tr>
<th>Feeder Number</th>
<th>Total Tons Produced</th>
<th>Tons Contributed to Overload Main</th>
<th>Number of Loads Carried</th>
<th>Belt Wait Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13308.00</td>
<td>0.00</td>
<td>4436</td>
<td>5.32</td>
</tr>
<tr>
<td>2</td>
<td>14628.00</td>
<td>0.00</td>
<td>4876</td>
<td>2.53</td>
</tr>
<tr>
<td>3</td>
<td>16134.00</td>
<td>0.00</td>
<td>5378</td>
<td>1.03</td>
</tr>
<tr>
<td>4</td>
<td>8519.50</td>
<td>0.00</td>
<td>3098</td>
<td>0.34</td>
</tr>
<tr>
<td>5</td>
<td>13482.00</td>
<td>0.00</td>
<td>4494</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>14655.00</td>
<td>0.00</td>
<td>4885</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>8486.50</td>
<td>0.00</td>
<td>3086</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>14310.00</td>
<td>0.00</td>
<td>4770</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>14436.00</td>
<td>0.00</td>
<td>4812</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>8302.25</td>
<td>0.00</td>
<td>3019</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total Tons Produced = 126261.25
Average Tons Per Shift = 2525.23
Variance in Shift Production = 11635.51

Total Tons Lost Due to Exceeding Allowable Load on Main = 0.00
Average Tons Per Shift = 0.00
Variance in Tons Lost Per Shift = 0.00
<table>
<thead>
<tr>
<th>Feeder Number</th>
<th>Total Tons Produced</th>
<th>Tons Contributed to Overload Main</th>
<th>Number of Loads Carried</th>
<th>Belt Wait Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13506.00</td>
<td>1101.20</td>
<td>4502</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>14454.00</td>
<td>914.07</td>
<td>4818</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>16095.00</td>
<td>470.65</td>
<td>5365</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>8841.25</td>
<td>591.36</td>
<td>3215</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>13335.00</td>
<td>600.28</td>
<td>4445</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>14244.00</td>
<td>386.89</td>
<td>4748</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>8571.75</td>
<td>128.49</td>
<td>3117</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>14025.00</td>
<td>52.63</td>
<td>4675</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>14553.00</td>
<td>0.00</td>
<td>4851</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>8698.25</td>
<td>0.00</td>
<td>3163</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total Tons Produced = 126323.25

Average Tons Per Shift = 2526.47

Variance in Shift Production = 10720.41

Total Tons Lost Due to Exceeding Allowable Load on Main = 4245.56

Average Tons Per Shift = 84.91

Variance in Tons Lost Per Shift = 238.40
Table 10

Results of Using Surge Control - 36 Inch Mother Belt
50 Shift Simulation

<table>
<thead>
<tr>
<th>Feeder Number</th>
<th>Total Tons Produced</th>
<th>Tons Contributed to Overload Main</th>
<th>Number of Loads Carried</th>
<th>Belt Wait Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13191.00</td>
<td>144.82</td>
<td>4397</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>14256.00</td>
<td>117.31</td>
<td>4752</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>15951.00</td>
<td>52.70</td>
<td>5317</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>8756.00</td>
<td>58.88</td>
<td>3184</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>13722.00</td>
<td>42.87</td>
<td>4574</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>15180.00</td>
<td>18.34</td>
<td>5060</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>8516.75</td>
<td>2.22</td>
<td>3097</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>14751.00</td>
<td>0.00</td>
<td>4917</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>14691.00</td>
<td>0.00</td>
<td>4897</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>8615.75</td>
<td>0.00</td>
<td>3133</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total Tons Produced = 127630.50
Average Tons Per Shift = 2552.61
Variance in Shift Production = 10632.24

Total Tons Lost Due to Exceeding Allowable Load on Main = 437.14
Average Tons Per Shift = 8.74
Variance in Tons Lost Per Shift = 9.26
Table 11
Results of Using Surge Control - 42 Inch Mother Belt 50 Shift Simulation

<table>
<thead>
<tr>
<th>Feeder Number</th>
<th>Total Tons Produced</th>
<th>Tons Contributed to Overload Main</th>
<th>Number of Loads Carried</th>
<th>Belt Wait Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13083.00</td>
<td>1.86</td>
<td>4361</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>14502.00</td>
<td>1.67</td>
<td>4834</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>15999.00</td>
<td>0.39</td>
<td>5333</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>8789.00</td>
<td>1.05</td>
<td>3196</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>13515.00</td>
<td>0.00</td>
<td>4505</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>15183.00</td>
<td>0.00</td>
<td>5061</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>8591.00</td>
<td>0.00</td>
<td>3124</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>14532.00</td>
<td>0.00</td>
<td>4844</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>14472.00</td>
<td>0.00</td>
<td>4824</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>8668.00</td>
<td>0.00</td>
<td>3152</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total Tons Produced = 127334.00
Average Tons Per Shift = 2546.68
Variance in Shift Production = 11572.65

Total Tons Lost Due to Exceeding Allowable Load on Main = 4.97
Average Tons Per Shift = 0.10
Variance in Tons Lost Per Shift = 0.07
<table>
<thead>
<tr>
<th>Belts Running Free</th>
<th>Average Shift Production (tons)</th>
<th>Average Load Spilled Per Shift (tons)</th>
<th>Average Feeder Belt Wait Per Shift (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Inch Mother</td>
<td>2535.70</td>
<td>140.58</td>
<td>0.00</td>
</tr>
<tr>
<td>36 Inch Mother</td>
<td>2531.84</td>
<td>20.18</td>
<td>0.00</td>
</tr>
<tr>
<td>42 Inch Mother</td>
<td>2531.84</td>
<td>0.51</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feeders Stopped</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Inch Mother</td>
<td>2481.66</td>
<td>0.00</td>
<td>80.79</td>
</tr>
<tr>
<td>36 Inch Mother</td>
<td>2519.95</td>
<td>0.00</td>
<td>11.39</td>
</tr>
<tr>
<td>42 Inch Mother</td>
<td>2525.23</td>
<td>0.00</td>
<td>0.18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Using Surge Controls</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Inch Mother</td>
<td>2526.47</td>
<td>84.91</td>
<td>0.00</td>
</tr>
<tr>
<td>36 Inch Mother</td>
<td>2552.61</td>
<td>8.74</td>
<td>0.00</td>
</tr>
<tr>
<td>42 Inch Mother</td>
<td>2546.68</td>
<td>0.10</td>
<td>0.00</td>
</tr>
</tbody>
</table>
**Table 13**

**Distribution of Load Buildup at the Mother Belt Head**

**Bin Discharge Rate**

<table>
<thead>
<tr>
<th>Load Buildup (tons)</th>
<th>Relative Frequency</th>
<th>Relative Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
<td>.465</td>
<td>.770</td>
</tr>
<tr>
<td>1 - 2</td>
<td>.128</td>
<td>.096</td>
</tr>
<tr>
<td>2 - 3</td>
<td>.098</td>
<td>.057</td>
</tr>
<tr>
<td>3 - 4</td>
<td>.080</td>
<td>.034</td>
</tr>
<tr>
<td>4 - 5</td>
<td>.062</td>
<td>.020</td>
</tr>
<tr>
<td>5 - 6</td>
<td>.046</td>
<td>.012</td>
</tr>
<tr>
<td>6 - 7</td>
<td>.034</td>
<td>.006</td>
</tr>
<tr>
<td>7 - 8</td>
<td>.024</td>
<td>.003</td>
</tr>
<tr>
<td>8 - 9</td>
<td>.017</td>
<td>.002</td>
</tr>
<tr>
<td>9 - 10</td>
<td>.012</td>
<td></td>
</tr>
<tr>
<td>10 - 11</td>
<td>.009</td>
<td></td>
</tr>
<tr>
<td>11 - 12</td>
<td>.006</td>
<td>less than</td>
</tr>
<tr>
<td>12 - 13</td>
<td>.005</td>
<td>.001</td>
</tr>
<tr>
<td>13 - 14</td>
<td>.004</td>
<td></td>
</tr>
<tr>
<td>14 - 15</td>
<td>.002</td>
<td></td>
</tr>
<tr>
<td>15 - 16</td>
<td>.002</td>
<td></td>
</tr>
<tr>
<td>16 - 17</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>17 - 18</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>18 - 19</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>19 - 20</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>20 - 30</td>
<td>&lt;.001</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B
MULTIFILE RUN
COMPILE RUN FORTRAN
DIMENSION CAPAPR(20), SPEED(20), WIDTH(20), DISMO(20),
1 XLEFE(20), CAPFE(20), ICOM(129), NPTS(20), Y(20, 30), CL(2
20), BO(20), CE(20), FO(20), BARX(20), SIGMA(20), CONST(20)
3. TWEN(20), TMOVE(2, 20), PROD(20), TIMLDD(20), OVERLO
4(20), BINMIS(20, 30), STOP1(20), STOP2(20), TOT1(20), TOT2
5(20), IBELT(20), STORE(20), NPROD(20), TPROD(20), TVERL
60(20), NTPROD(20), TRAVTB(20), TRAVTM(20), WAIT(20),
7STOP(20), BSTOP(20), WT(20), WTLIM(20), TBSTOP(20), TW
8AIT(20), TIMLDD(20), TIBELD(20), PARAM(20)
READ 501, ICOPY
CALL COPY B(ICOPY)
READ 501 ISAVE
CALL SETRND(ISAVE)
READ 501 NFEED
100 READ 502 IROUTE
!F(IROUTE)=2, 2, 3
2 CALL SAVRND(ISAVE)
CALL COPY E
PUNCH 601 ISAVE
601 FORMAT(110, 5HISAVE)
PRINT 602
602 FORMAT(1HO 19HSimulation completes)
STOP
3 CALL ACOMP(ROUTE, 1, 1HD, 1, 1, KEY)
GO TO(4 5 7 2) KEY
C **** READ IN DATA FOR (BIN STORAGE)
4 READ 501, NRAY
READ 503 HINTBC
READ 503 (CAPAPR(I), 1=1 NRAY)
GO TO 100
C **** READ IN (DATA FOR BELTS)
5 READ 501 NFEED
READ 503 SIZEM SPEDM CAPMO XLENMO
READ 503 (SPEED(I), 1=1 NFEED)
READ 503 (WIDTH(I), 1=1, NFEED)
READ 503 (DISMO(I), 1=1, NFEED)
READ 503 (XLEFE(I), 1=1, NFEED)
READ 503 (CAPFE(I), 1=1, NFEED)
READ 503 (WTLIM(I), 1=1, NFEED)
DO 6 1=1, NFEED
TRAVTM(I) = DISMO(I)/SPEDM
6 TRAVTB= XLEFE(I)/SPEED(I)
   GO TO 100
7 CALL ACOMP(ROUTE, 1, IH1, 1, 1, KEY)
   GO TO(14, 8, 9, 2, KEY)
C 44: READ IN (HEADING) FOR PROBLEM
8 CALL HEDING(1COM)
   GO TO 100
9 CALL ACOMP(ROUTE, 1, IH1, 1, 1, KEY)
   GO TO(10, 12, 2, 2, KEY)
C 44: READ IN DATA FOR (PROBABILITY DISTRIBUTIONS)
10 READ 503. (PARAM(I) , I=1, NFEED)
   IF(PARAM(I)) 101, 101, 100
101 READ 506 (NPTS(I) , I=1, NFEED)
   DO 11 I=1, NFEED
      NPT= NPTS(I)
11 READ 503. (Y(I, J) , J=1, NPT)
   READ 504 (CH(I) , BO(I) , GE(I) , FO(I) , J=1, NFEED)
   GO TO 100
C 44: READ IN DATA FOR (SHUTTLE CARS)
12 READ 503. (BARX(I) , I=1, NFEED)
   READ 503. (SIGMA(I) , I=1, NFEED)
   READ 503. (CONST(I) , I=1, NFEED)
   GO TO 100
C 44: READ IN GENERAL DATA
14 READ 505. SHIFTL, NSHIFT, ISHIFTL, ISTOP
   S1F1LE=SHEFTL, 60,
   PRINT 603, XLENMO, SIZEM, SPEDM, CAPMO
603 FORMAT(IH1, 5X, 17HMAIN BELT SUMMARY/1H0, 10X, 8HLE
   NGTH, 3HFt., F22.2/1H, 10X, 10HWIDTH, 1N., F23.2/1H, 10X,
   215HSPEED, FT./MIN. F18.2/1H, 10X, 16HALLOWABLE LOAD,
   38HT./HR., F9.2//1H0, 5X, 19HFEEDER BELT SUMMARY/1H0,
   410X, 10HFEEDER NO., 8X, 11HLNGTH FT., 8X, 10HWIDTH
   5'N. 4X 15HSPEED, FT./MIN., 3X, 24HDIS. FROM MAIN HEAD
   6, FT., 3X, 22HALLOWABLE LOAD, T./HR., //)
   PRINT 604, (1, XLEFE(I), WIDTH(I), SPEED(I), DIxMO(I), CAPFE
   IH1, 1, NFEED)
604 FORMAT(IH1, 120, F19.2, F18.2, F19.2, F27.2, F25.2)
501 FORMAT(8110)
502 FORMAT(A1)
503 FORMAT(10F8.0)
504 FORMAT(4F10.0)
505 FORMAT(F4.0, 314)
506 FORMAT(2014)
C 44: BEGIN SIMULATION
   SUMT = 0
   SUML = 0
   STISQ = 0
   STL = 0
   SLISQ = 0
SLJ=0
SPISQ=0
SPJ=0
NUM=0

C *** GENERATE STARTING TIMES FOR PRODUCTION
200 DO 15 1=1, NFEED
   XYZ=DUMP(Y, 1, NPTS, CI, BO, CE, FO, PARAM)
   TOT1(I)=XYZ*TRAVTB(I)+TRAVTM(I)
   TIMOVE(1, I):=TOT1(I)
   IF(SIGMA(I)) 202, 202, 201
202 TIMLD(I)=BARX(I)
   TIMLD2(I)=-BARX(I)
   GO TO 203
201 TIMLD(I)=-TLOAD(BARX, SIGMA, I)
   TIMLD2(I)=-TLOAD(BARX, SIGMA, I)
203 TIMOVE(2, I)=TIMOVE(1, I)+TIMLD(I)
   NPROD(I)=NPROD(I)+1
   TWEN(I)=DUMP(Y, I, NPTS, CI, BO, CE, FO, PARAM)
   TOT2(I)=TOT1(I)+TWEN(I)
   PROD(I)=TIMLD(I)*CONST(I)
   NUM=NUM+1
   TIME:=0
   IF(SIGMA(I)) 306, 306, 307
C *** CHECK IF ANY LOAD TAILS ARE ZERO
300 DO 17 I=1, NFEED
   IF(STOP(I)) 950, 950, 904
904 STOP1(I)=TIME-SMALL-TRAVTM(I)
   STOP2(I)=TIME-TRAVTM(I)
   IF(TOT2(I)-STOP2(I)) 905, 950, 950
905 IF(TOT2(I)-STOP1(I)) 901, 908, 908
908 WT(I)-STOP2(I)-TOT2(I)+WT(I)
   GO TO 950
901 IF(TOT2(I)=-TIMLD2(I)-STOP1(I)) 950, 950, 902
902 WT(I)-STOP1(I)+WT(I)
950 STOP'(I)=0
   IF(TIMOVE(2, I)) 16, 16, 17
16 TIMOVE(1, I)=TWEN(I)-TIMLD(I)
   IF(TIMOVE(1, I)) 951, 951, 952
951 TIMOVE(1, I)=0
952 TWEN(I)=DUMP(Y, I, NPTS, CI, BO, CE, FO, PARAM)
C *** SEE IF SECT HAS TO WAIT
   IF(WT(I)) 160, 161, 161
161 TWEN(I)=TWEN(I)+WT(I)
   WAIT(I)=WT(I)-WTLIM(I)+WAIT(I)
   WT(I)=0
306 TIMLD(I)=BARX(I)
   TIMLD2(I)=-BARX(I)
GO TO 308

307 TIMLD(1):=TIMLD2(I)
TIMLD2(I) = TLOAD(BARX, SIGMA, I)

308 TIMOVE(2, J) := TIMOVE(1, I) + TIMLD(I)
NPROD(I) := NPROD(I) + 1
PROD(I) := PROD(I) + TIMLD(I) * CONST(I)

17 CONTINUE

C้น rel = FIND LOADS AT MAIN BELT HEAD (ZERO LOADS)
400 ICNT := 0
DO 20 I = 1, NFEED
1F(TIMOVE(1, I)) 20, 19, 20
19 IF(TIMOVE(2, I)) 20, 20, 195
195 ICNT := ICNT + 1
'CNT := ICNT + 1

C้น rel = FIND SMALL - LENGTH OF OR TIME BETWEEN LOADS
SMALL := 10000.
DO 23 I = 1, 2
DO 23 J = 1, NFEED
IF(SMALL - TIMOVE(I, J)) 23, 23, 21
21 IF(TIMOVE(I, J)) 23, 23, 22
22 SMALL := TIMOVE(I, J)
23 CONTINUE

C้น rel = SUBSTRACT SMALL FROM ALL TIMOVE
DO 26 I = 1, 2
DO 26 J = 1, NFEED
TIMOVE(I, J) := TIMOVE(I, J) - SMALL
IF(TIMOVE(I, J)) 25, 26, 26
25 TIMOVE(I, J) = 0
26 CONTINUE

C้น rel = FIND LOAD DENSITIES ON MAIN BELT
IF(ICNT) 30, 30, 27
30 DNSTY := 0
GO TO 401

27 DNSTY := 0
X MUCH := CMX / 60.
DO 29 I = 1, ICNT
JJ := ICNT + 1 - I
II := BELT(JJ)
DNSTY := CONST(I) + DNSTY
IF(DNSTY - SMUCH) 29, 29, 28
28 IF(ISTOP) 281, 281, 282
282 TIMOVE(2, II) := TIMOVE(2, II) + SMALL
STOP(II) := SMALL
BSTOP(II) := BSTOP(II) + SMALL
DNSTY := DNSTY - CONST(I)
GO TO 284
281 OVERLO(II) := (DNSTY - SMUCH) * SMALL + OVERLO(II)
284 X MUCH := DNSTY
29 CONTINUE
C ::::FIT BIN CAPACITY TO DISTRIBUTION
401 DO 33 I=1, NRAY
   STORE(I) = SMALL(DNSTY * CAPAPR(I))
   IF(STORE(I)) = 31, 32, 32
31 STORE(I) = 0
32 IP4 = STORE(I) / HINTBC + 1.
   IF(IP4-30) = 33, 33, 320
320 IP4 = 30
33 BINHIS = IP4 * BINHIS(IP4)+1.
   GO TO (34, 38), IFIN
34 TIME = TIME * SMALL
   IF(TMME SIFTLE) = 300, 37, 37
C ::::ADD WHAT IS LEFT ON BELT TO PRODUCTION
37 IFIN = 2
38 DO 39 I=1, NFEED
   IF(TIMOVE(I, I)) = 39, 39, 400
39 CONTINUE
   SUMP = 0
   SUMO = 0
   DO 40 I=1, NFEED
      SUMP = SUMP + PROD(I)
40 SUMO = SUMO + OVERLO(I)
   DIFF = SUMP - SUMO
   PER = SUMO / SUMP * 100.
C ::::PRINT RESULTS OF SIMULATION - SHIFT SUMMARY
46 PRINT 605, NUM, SHIFTL
605 FORMAT(1H1, 52X, 22(1H8)/53X, 17HSUMMARY FOR SHIFT,
   115/1H0, 50X, 18HPRODUCTION SHIFT=, F5.2, 5H HRS. /51X28
   2(1H8))
   PRINT 606
606 FORMAT(1H10, 10X, 10HFEEDER NO., 10X, 10HTOTAL TONS,
   14X, 16HTONS CONTRIBUTED, 6X, 15HNUMBER OF LOADS, 11
   2X 9HBELT WAIT. 10X, 10HSEC. WAIT /1H . 30X, 8HPRODUC
   3ED. 6X, 16HTO OVERLOAD MAIN, 6X, 7HCARR1ED, 19X, 7HMI
   4NUTES. 12X, 7HMINUTES/))
   PRINT 607. (1, PROD(I), OVERLO(I), NPROD(I),
   15STOP([I, WAIT(I), 1=1, NFEED])
607 FORMAT(1H1, .120, 2F20. 2, 120, 2F20. 2)
   PRINT 608, SUMP, SUMO, DIFF, PER
608 FORMAT(///IH, 10X, 19HTOTAL TONS PRODUCED, F17. 2/
   11H0, 10X, 22HTOTAL TONS LOST DUE TO/13X, 19HEXCEEDI
   2NG ALLOWABLE/13X, 12HLOAD ON MAIN, F22. 2/11H0, 10X,
   310HPRODUCTION, 1X, 11HREALIZED AT/13X, 17HMAIN HEA
   4D WITHOUT/13X, 22HEXCEEDING ALLOWED LOAD, F12. 2/
   511H0, 10X, 2(1HIPERCENTAGE PRODUCTION LOST, F10. 2)
C ::::COLLECT DATA FOR MEAN AND VARIANCE
47 SUMP = SUMP + SUMP
SUML = SUML + SUMO
STISQ = STISQ + SUMP * 2
STI = STI + SUMP
SLISQ = SLISQ + SUMO * 2
SLI = SLI + SUMO
SPISQ = SPISQ + DIFF * 2
SPI = SPI + DIFF

DO 41 1 = 1, NFEED
TPROD(1) = TPROD(1) + PROD(1)
TVERLO(1) = TVERLO(1) + OVERLO(1)
NTPROD(1) = NTPROD(1) + NPROD(1)
TBSTOP(1) = TBSTOP(1) + BSTOP(1)
TWAIT(1) = TWAIT(1) + WAIT(1)
WAIT(1) = 0
BSTOP(1) = 0
PROD(1) = 0
OVERLO(1) = 0
WAIT(1) = 0
STOP(1) = 0
TBSTOP(1) = 0
TIBELD(1) = 0

41  NPROD(1) = 0

C *** TEST FOR END OF SIMULATION

IF (NUM - NSHIFT) > 200, 42, 42

C *** PRINT FINAL RESULTS

42 PRINT 609, NUM, SHIFTL

609 FORMAT(1H1, 52X, 24(1H*), 1H, 52X, 16HTOTAL SIMULATION,
18H SUMMARY /1H0, 49X, 3HFOR, 13. 10H SHIFTS AT , F5. 2, 1X,
28HRS. PER /1H0, 56X, 16HPRODUCTION SHIFT /57X, 16(1H*))

PRINT 606
PRINT 607, (1, TPROD(1), TVERLO(1), NTPROD(1),
1TBSTOP(1), TWAIT(1), 1 = 1, NFEED)

C *** CALCULATE MEAN AND VARIANCE

BUM = NUM
XBAR = SUMT / BUM
VAR = (BUM - STISQ - STI * 2) / (BUM - (BUM - 1.))

PRINT 610, SUMT, XBAR, VAR

610 FORMAT(///1H1, 10X, 19HTOTAL TONS PRODUCED, F21. 2/1H
10 10X, 22HVERAGE TONS PER SHIFT, F13. 2/1H010X, 28HVA
2RIANCE IN SHIF PRODUCTION, F12. 2///)

XBAR = SUML / BUM
VAR = (BUM - SLISQ - SLI * 2) / (BUM - (BUM - 1.))

PRINT 611, SUML, XBAR, VAR

611 FORMAT(///1H1, 10X, 22HTOTAL TONS LOST DUE TO /13X, 19
1HEXCEEDING ALLOWABLE /13X, 12HLOAD ON MAIN, F26. 2/
21H0 10X, 22HVERAGE TONS PER SHIFT, F18. 2/1H), 10X, 31
3IVARIANCE IN TONS LOST PER SHIFT, F9. 2///)

XBAR = SPI / BUM
VAR = (BUM - SPISQ - SPI * 2) / (BUM - (BUM - 1.))
SUMP::SUMT::SUMU
PRINT 612, SUMP, XBAR, VAR
612 FORMAT(1H10, 1X, 22HPRODUCTION REALIZED AT/13X, 17
1HMAIN HEAD WITHOUT/13X, 22HEXCEEDING ALLOWED LOAD,
2F16.2/11H10 10X, 22HAVERAGE TONS PER SHIFT, F18.2/1H0,
310X, 22HVAARIANCE IN SHIFT PRODUCTION, F12.2////)
PER=SUMP/SUMT*100.
PRINT 613, PER
613 FORMAT(1H10, 1X, 26HPERCENTAGE PRODUCTION LOST, F
114. 2)
DO 45 I=1, NRAY
45 PUNCH 617 CAPAPR(I, (BINHIS(I, J) = J=1, 30)
617 FORMAT(E16.8, 6HCAPAPR / (5E16.8))
DO 9999 I=1, 20
TPROD(I)=0
TVFRLO(I)=0
NTPROD(I)=0
TSTOP(I)=0
9999 TWAIT(I)=0
GO TO 100
END

COMPILE RUN FORTRAN
FUNCTION DUMP(Y, NA, NPTS, CI, BO, CE, FO, PARAM)
DIMENSIONY(20, 30), NPTS(20), CI(20), BO(20), CE(20), FO(20)
PARAM(20)
IF(PARAM(NA))=10, 10, 11
10 X-RANDF(100.)
N1=NPTS(NA) - 1
DO 1 J=2, N1
1 CONTINUE
DUMP=FO(NA)+(X-Y(NA, J) / (100. - Y(NA, J)): CE(NA)
RETURN
2 DUMP: (X-Y(NA, J - 1)) / (Y(NA, J) - Y(NA, J - 1)): CI(NA) + FLOATF(J
1 2): CI(NA) + BO(NA)
RETURN
11 DUMP PARAM(NA): LOGF(1. - RANDF'1.))
RETURN
END

COMPILE RUN FORTRAN
FUNCTION TLOAD(BARX, SIGMA, IB)
C **:
C **: GENERATES LOAD LENGTH ALONG BELT ACCORDING TO
C **: A NORMAL DISTRIBUTION
DIMENSION BARX(20), SIGMA(20)
X: RANDF(1.)
TLOAD: SQRTF(-2. * LOGF(X)) * COSF(6. 2831853*X): SIGMA(IB)
1+ BARX(IB)
RETURN
END

COMPILE RUN FORTRAN
SUBROUTINE HEDING(ICOM)
C BLANK CARD TERMINATES PRINTING
DIMENSION ICOM(130)
C EACH PRINTED LINE OCCUPIES 2 DATA CARDS
PRINT 601
601 FORMAT(1H1)
   1 J=1
      READ 501, (ICOM(I), I=1, 129)
501 FORMAT(80A1)
   2 DO 4 I=1, 129
      J=130-I
      I=ICOM(I)
   3 JJ=JJ+1
   4 CONTINUE
   5 JJ=JJ/2+1
      DO 7 I=1, JJ
      DO 6 II=1, 128
         III=130-II
      6 ICOM(III)=ICOM(III-1)
      7 ICOM(I)=0
         PRINT 602, (ICOM(I), I=1, 129)
602 FORMAT(1H0, 129A1)
      GO TO 1
   8 RETURN
END

MULTIFILE END

Input controls in the order which they are read by the computer follow:

BIN STORAGE--Control for the following surge facility data
   NRAY--Number of cells in histogram
   HINTBC--Cell interval in histogram
   CAPAPR(I)--Surge output rate

DATA FOR BELTS--Control for the following belt data
   NFEED--Number of feeder belts
   SIZEM--Width of mother belt
   SPE:DM--Speed of mother belt
   CAPMO--Capacity of mother belt
XLENMO -- Length of mother belt
SPEED[I] -- Speed of feeder belts
WIDTH[I] -- Width of feeder belts
DMSD[I] -- Distance of feeders from mother belt head
XLFES[I] -- Length of feeder belts
CAPFE[I] -- Capacity of feeder belts
WTLIM[I] -- Time feeder can wait before holding back production

HEADING -- Control for any heading to be printed
ICOM[I] -- Array that stores heading

PROBABILITY DISTRIBUTIONS -- Control for the following shuttle car arrival distributions
PARAM[I] -- Mean value of fitted distribution
NPTS[I] -- Number of cells in each distribution
Y[I,J] -- Distributions for shuttle car arrivals in each section
C[I] -- Cell size (Y[I,J])
BO[I] -- Lower boundary (Y[I,J])
CE[I] -- Cell size (extreme values, Y[I,J])
FO[I] -- Lower boundary (extreme values, Y[I,J])

SHUTTLE CARS -- Control for the following shuttle car data
BARX[I] -- Mean shuttle car unloading times
SIGMA[I] -- Standard deviation of shuttle car unloading rate
CONST[I] -- Mean shuttle car unloading rates

END -- Control to read in the following data and proceed with the simulation
SHIFTL -- Expected shift length
NSHIFT -- Number of simulated shifts
IPSHIF -- Control to print results of each shift
ISTOP -- Control to stop feeder belts
APPENDIX C
Analysis of Alternate Computer Program

In order to illustrate how this simulation model works, consider a feeder belt 500 feet long, moving with a speed of 10 feet per second. A two dimensional array is used to store the following information with the rows designating the feeder number and the columns representing seconds of travel along the belt. The number of positions used in the array columns represents the number of seconds for the carrying run of the belt to move from the tail to the head.

Now consider a shuttle car requiring 30 seconds to discharge a load of 3.0 tons. Assuming a constant discharge rate, the shuttle car would unload:

\[
\text{Tons} = \frac{3.0 \text{ tons}}{30 \text{ sec}} = 0.1 \text{ tons/sec.}
\]

This shows that for every second the feeder belt operates it carries 0.1 tons for 10 feet. Since values in the array are in seconds, the array column representing this feeder belt would resemble the figure below, with each numeral 1 designating 0.1 tons for the purpose of illustration. The computer would actually have 0.1 stored in these positions.

00000000000000000000111111111111111111111111111111111

This load may be moved along the belt simply by shifting all positions ahead one second, and after a time lapse of, say 10 seconds, the load would be stored in the computer as shown below, again with each numeral 1 representing 0.1 tons.
The mother belt is represented in a similar manner, and in order to transfer a load from a feeder belt to the mother belt, the front position of the feeder array is added to the appropriate position on the mother belt array. If no load is discharging a zero would be added effecting no change on the mother belt. The magnitude of the new number can be investigated to determine if the mother belt has been overloaded. The advantage of this type of simulation is that every event in the system can be incremented by one second and no complex situations have to be considered. The main disadvantage for its use in this study was the excessive computer time required for a 10 feeder belt system.
Appendix D

Part 1 - Monte Carlo Sampling Routine

The Monte Carlo technique consists of a new use derived from an old expression—unrestricted random sampling. This procedure involves the selection of items from some population drawn in such a manner that each item in the population has an equal probability of being selected.

A sampling plan of this nature consists of playing a game with a man-made system in which an experiment is to be simulated. The events under study are generated randomly, and placed into frequency patterns to produce some expected future condition, dependent upon past operating performances. Results from this simulated data are then compared in order to arrive at an optimum solution.

The procedure of drawing an item at random from a universe described by some probability density \( f(x) \) can be illustrated as follows:

1. Plot the distribution function \( F(x) \) as shown in the figure below, where \( F(x) = \int_{-\infty}^{x} f(u) \, du \).
Choose a random decimal \( (F(x_1)) \) between 0 and 1 from a table of random numbers (Brunk 1960).

Project the random decimal horizontally until the projection intersects the distribution curve.

Record the corresponding random variable, \( x_1 \).

This procedure is then repeated using different random decimals whenever a new sample is needed for continuing the simulation. In general, the more samples that are generated in this fashion, the more closely the distribution of samples will approach the density function \( f(x) \).

In order to justify this procedure, consider the probability of ending up with a measurement between \( x \) and \( x + dx \) being proportional to \( f(x) \). Referring to the figure below:

\[
\begin{align*}
\text{dy}_1 & \quad \text{dy} \\
\text{x}_1 & \quad \text{x}_1 + dx
\end{align*}
\]

\[
P \left[ x_1 < \text{resulting } x < x_1 + dx \right] = dy_1 \quad (1)
\]

Differentiating \( F(x) \) with respect to \( x \) gives:

\[dy = F'(x) = f(x) \, dx\]

Allowing \( x \) to assume the value of \( x_1 \):

\[dy_1 = f(x_1) \, dx \quad (2)\]
and substituting \( f(x_1) \, dx \) from equation (2) into equation (1) for \( dy_1 \) results in:

\[
P \left\{ x_1 < \text{resulting } x < x_1 + dx \right\} \approx f(x_1) \, dx
\]

This resulting equation shows that in repeated sampling the values of the random variable \( x \) will tend to follow the form of the density function, \( f(x) \) (Sasieni, Yaspan and Friedman 1959).
Appendix D

Part 2 - An Example of Model Assumptions and Calculations

The mechanics of simulation and the method of attack for this specific investigation is provided for in the following sample problem, using a hand-computational routine.

Consider a three feeder parallel belt network with the following input parameters:

1. Shuttle car arrival times. These define the arrival rate of material to the belt system and are shown below as distribution functions for the individual sections.

   ![Distribution Functions](distribution_function.png)

   Production Miner
   \[ B = 0.5 \]
   \[ C = 2.0 \]

   Production Miner
   \[ B = 0.5 \]
   \[ C = 2.0 \]

   Development Miner
   \[ B = 0.5 \]
   \[ C = 2.0 \]

2. Shuttle car capacities and discharge times. These are also defined as distribution functions; however, for the purpose of this investigation, 3.0 tons per trip and 0.50 minutes, which are the expected values, respectively, are used. These values result in an average discharge rate of 6.0 tons per minute.
(3) **Conveyor belt specifications.** The tabular listing below provides the remaining input information. These include dimensions and other physical limitations which have to be considered.

<table>
<thead>
<tr>
<th>BELT SIZE (in)</th>
<th>SPEED (ft/min)</th>
<th>CAPACITY (tons/min)</th>
<th>DISTANCE FROM MOTHER HEAD (ft)</th>
<th>LENGTH (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mother - 36</td>
<td>300</td>
<td>10.0</td>
<td>-</td>
<td>750</td>
</tr>
<tr>
<td>Feeder 1 - 30</td>
<td>250</td>
<td>7.0</td>
<td>300</td>
<td>250</td>
</tr>
<tr>
<td>Feeder 2 - 30</td>
<td>250</td>
<td>7.0</td>
<td>500</td>
<td>150</td>
</tr>
<tr>
<td>Feeder 3 - 30</td>
<td>250</td>
<td>7.0</td>
<td>750</td>
<td>250</td>
</tr>
</tbody>
</table>

At the onset, an initial analysis is necessary to determine the time \( T_1 \) for each load to travel from the shuttle car discharge point to the mother belt head. These calculations are as follows:

\[
T_1 = \frac{\text{Feeder length}}{\text{Feeder speed}} + \frac{\text{Mother length}}{\text{Mother speed}}
\]

\[
T_1 = \frac{250}{250} + \frac{300}{300} = 2.00 \text{ min.}
\]

\[
T_2 = \frac{150}{250} + \frac{500}{300} = 2.27 \text{ min.}
\]

\[
T_3 = \frac{250}{250} + \frac{750}{300} = 3.50 \text{ min.}
\]

This analysis initializes the computational format and allows the simulation to proceed in the following fashion.

The first stage of simulation generates an arrival time for each shuttle car. Three random numbers (0.95, 0.73 and 0.15) are chosen from a random-number table (Brunk 1960), and compared with the ordinate values (probabilities) for the previously shown distribution functions. These functions are stored in the memory of the computer in an array, \( S_{ij} \). Each random number \( R_i \) is compared with each \( S_{ij} \) value to find \( S_{i,k-1} \leq R_i \leq S_{i,k} \). The random variable, \( A_i \).
located on the abscissa (shuttle car arrival time) is determined from the lower boundary value, $B_i$, and the cell interval, $C_i$
(assuming equal cells), as follows:

$$A_i = \frac{(R_i - S_i, k-1)}{(S_{ik} - S_i, k-1)} C_i + (K - 2) C_i + B_i$$

$$A_1 = \frac{(.95 - .85)}{(1.00 - .85)} 2.00 + (4 - 2) 2.00 + .50 = 5.84$$

$$A_2 = \frac{(.73 - .70)}{(1.75 - .70)} 2.00 + (3 - 2) 2.00 + .50 = 3.70$$

$$A_3 = \frac{(.15 - .00)}{(2.20 - .00)} 2.00 + (2 - 2) 2.00 + .50 = 2.00$$

Using the previous results for $T_i$, the times ($H_i$) for which these arrivals will reach the mother belt head are:

$$H_i = A_i + T_i$$

$$H_1 = 5.84 + 2.00 = 7.84 \text{ min.}$$

$$H_2 = 3.70 + 2.27 = 5.97 \text{ min.}$$

$$H_3 = 2.00 + 3.50 = 5.50 \text{ min.}$$

This information describes the relative positions of each arrival in the belt system and is computer-stored in a two-dimensional array, $Z_{ij}$, with $i$ defining the head and tail of each load and $j$ the feeder belt number.

At this stage, a necessary assumption is made concerning the $Z_{ij}$ values, which considers each load independent of all other loads in the system, i.e., each load passes through the network without being influenced by any other load until it reaches the mother belt terminus. This phenomenon may be clarified if one visualizes a separate mother belt for each section, which allows one to identify
events that would have happened if the loads arrived on the same belt. From the sample problem, the values assigned to this array are listed below:

Matrix I

<table>
<thead>
<tr>
<th>Feeder</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head (1)</td>
<td>7.84</td>
<td>5.97</td>
<td>5.50</td>
</tr>
<tr>
<td>Tail (2)</td>
<td>8.34</td>
<td>6.47</td>
<td>6.00</td>
</tr>
</tbody>
</table>

Working under the above assumptions, Matrix I is altered on the basis of moving time forward. This is assigned on the smallest element in the matrix, i.e., the first load to reach the mother belt terminus which, in this case, is 5.50 minutes for Feeder 3. The time for Feeder 3 is then subtracted from all other elements in the matrix and the results are shown in Matrix II:

Matrix II

<table>
<thead>
<tr>
<th>Feeder</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head (1)</td>
<td>2.34</td>
<td>0.47</td>
<td>0.00</td>
</tr>
<tr>
<td>Tail (2)</td>
<td>2.84</td>
<td>0.97</td>
<td>0.50</td>
</tr>
</tbody>
</table>

The zero element in [1,3] indicates that a load from Feeder 3 has reached the terminus; however, no decision event (overlapping) has taken place and a third iteration is performed.

The smallest (non-zero) time, 0.47 minutes in [1,2] is selected.
and subtracted from all remaining elements. As a result, a zero appears in [1, 2] and a negative element in [1, 3]. This negative element is transformed to a zero value and the resulting matrix is shown below:

\[
\begin{array}{c|cc}
\text{Feeder} & 1 & 2 & 3 \\
\hline
\text{Position} & & & \\
\text{Head (1)} & 1.87 & 0.00 & 0.00 \\
\text{Tail (2)} & 2.37 & 0.50 & 0.03 \\
\end{array}
\]

This situation is interpreted as representing 0.47 minutes of the load from Feeder 3 passing the mother belt head, and further, the load from Feeder 2 reaching this point.

Since a load from only one belt has passed the mother belt head, no overloading occurred, and another iteration is performed. The smallest element, 0.03 in [2, 3], is again subtracted from all elements. The new array after all resulting transformations is shown in Matrix IV:

\[
\begin{array}{c|cc}
\text{Feeder} & 1 & 2 & 3 \\
\hline
\text{Position} & & & \\
\text{Head (1)} & 1.84 & 0.00 & 0.00 \\
\text{Tail (2)} & 2.34 & 0.47 & 0.00 \\
\end{array}
\]

The information from this array is somewhat different from the
previous two since 0.03 minutes of load from both Feeders 2 and 3 have passed the mother belt head. Consequently, an overloaded condition might have occurred, resulting in the following necessary test. Since the total flow rate for both feeder belts is

\[(2)(6 \text{ tons/minute}) = 12.0 \text{ tons/minute}\]

and the mother belt capacity is 10.0 tons per minute, the mother belt would have been overloaded for 0.03 minutes by

\[(12 \text{ tons/min.} - 10 \text{ tons/min.})(0.03 \text{ min.}) = 0.06 \text{ tons}.\]

The third column of the above array contains zeros, meaning that the service for this particular feeder has been completed. Consequently, a new load must be generated for this belt using the Monte Carlo sampling method previously outlined. This iterative process and numerical analysis is repeatedly performed until the end of the simulated shift is reached, after which the total effects produced in the system are retrieved. In the case where it is desired to stop the feeder belts rather than overload the mother belt, the loads are frozen in position until they can pass the mother belt head without producing an overload.

There are numerous other calculations performed in the computer program which differ in order and complexity than the ones presented here. However, this sample calculation should serve to illustrate the basic reasoning involved in this simulation model.