'MATERIAL MANAGEMENT

DECISION SUPPORT MODEL

by

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A Material Management Decision Support System is applied to a case study distribution facility. The system is formulated within the framework of an algorithm that consists of two primary steps.

The first step utilizes a simulation model to analyze the impact of three management policies that implement material handling equipment in the distribution facility. The simulated results of each policy represent a database of performance measure values.

The second step utilizes a decision model to evaluate the set of policy alternatives. In this step, the user is required to rank order and assign relative weights to decision parameters. A value function is computed for each alternative using this information, the simulated performance measures and non-model parameters. Output for the model is in terms of rank ordered numerical worths that designate the final selection alternative based on the decision maker's preferences.
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Finally, I would like to express my thanks and appreciation to who typed this document.
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CHAPTER 1

INTRODUCTION

Sage [41] provides a guideline for designing decision support information systems in a three-step process:

1. Formulate the issue.
   A) Problem definition (determine needs, constraints, and alterables).
   B) Value system design (determine objectives and performance measures).
   C) System synthesis (identify possible action alternatives and measures of these).

2. Analyze the issue.
   A) Systems analysis and modeling (determine the structure and boundaries of the decision situation).
   B) Optimize and refine alternatives (ensuring that alternatives are in best accord with desired system performance levels).

3. Interpret the issue.
   A) Evaluate and decision making (prioritization of feasible alternatives).
   B) Planning for action (commitment to implement chosen alternatives.

This research is directed towards applying the above methodology in a materials management environment.
The material management operations of a large government contractor are used for a case study in this application. A 49,000 square-foot Materials Distribution Center (MDC) provides the warehousing and material management operations that are typical of industrial material distribution systems. The MDC can be described as a network of operating stations that perform services on incoming materials. Identifying materials, inspection, movement, storage and retrieval operations are the primary responsibilities of the distribution center.

A computerized simulation model of these operations gives management the capability to investigate the effects of alternative manual, semi-automatic, and automatic work methods in the distribution process and completes the essentials of step 1 and step 2 in designing the decision support system. A direct assessment technique of multiattribute utility theory is used to evaluate trade-offs associated with implementing material handling equipment alternatives (computed directly in the simulation model) and other important decision parameters (not computed in the model) such as cost.

Multiattribute utility theory is based on a "decision rule" that attempts to consider all aspects of a decision situation by means of disaggregating the various choice components [41]. This construct is analogous to step 3 of the system design procedure and when combined with the simulation model, represents the total system of decision support for material management functions.
1.1 **Problem Statement.**

The government contractor providing the case study is investigating several policies aimed at reducing material throughput time in the MDC. Throughput time is the time required to receive materials to stock plus the time required to retrieve materials from storage. The policies require installing material handling equipment into the Receiving and Stockroom operations in the distribution network. Presently, there is no management analysis tool to study the interrelationships that exist between these operations that will predict the impact of implementing management policies. Without a "network view" of all distribution workcenters the ability to effectively evaluate trade-offs associated with policy implementation is constrained and misallocation results. A system is needed that characterizes the operations of the entire distribution network. This system should report key interrelationships between workcenters and evaluate the significance of changing operating methods on system throughput.

The following policy alternatives are of interest to the MDC managers:

1. Attempt to reduce manual paperwork operations on the receiving floor. To accomplish this, examine barcode scanning devices in the most appropriate workcenters.

2. Consider the impact of alternative material transport mechanisms for UPS materials. Note that hourly reductions for throughput time will be the primary consideration for
converting to more costly measures.

3. Introduce work improvement programs in the MDC Stockroom.

Determine the degree of throughput minimization achieved from (A) Carousel System versus (B) ASRS installation.

In summary, a tool is needed that describes the impact of material management policies on the MDC. This tool should also assist management in evaluating the given set of alternatives and selecting a policy for final implementation.

1.2 Research Objectives.

The overall objective of this research focuses on developing a decision support system for planning and policy evaluation in a materials management environment. Translating the general guidelines described by Sage [41] into a specific set of requirements, the following specific research objectives are identified:

1. Develop a management planning and analysis tool for a representative case study. This objective refers to designing a fully operational simulation model characterizing the operations of the MDC. To accomplish this objective, information on the type, rate, volume, and distribution of work flow is gathered. This type of analysis is achieved by on site inspection of the operations and extensive interviews with all levels of staff that are responsible for material movement.

2. Develop a general approach for representing policy and equipment alternatives within the framework of objective one.
This objective is attained by providing a step by step procedure for executing the simulation model. Also included as part of this objective is the development of a decision model that provides a systematic means for quantifying the comparative importance of material management performance measures.

3. Implement the algorithm composed from objective 1 and 2 into the industrial case study environment. This objective is attained by integrating the results from simulation analysis on material handling policy alternatives with the processing capabilities of the decision model. Selecting a policy for implementation based on management preferences completes the application of the algorithm.

1.3 Research Overview.

The following chapters are included in this research document: the Literature Review, The Modeling Approach, Decision Support System Implementation, Empirical Analysis Using the Decision Support System and Conclusions and Recommendations. Each topic presents both general information and details specific to the case study environment. The Literature Review is directed towards research pertinent to simulation model building and language selection, material handling equipment that might provide enhanced operating levels in the MDC, and Decision Theory which introduces multiattribute value function constructs. Each topic contributes to the development of the research.
Chapter 3 describes the methodological framework followed in design of the Decision Support System. The chapter includes a description of the case study distribution operations and the determination of system performance measures. The formal Material Management Decision Support System Algorithm is also introduced and accompanied by an example.

Chapter 4 contains a detailed description of the simulation studies on material handling equipment. Specifically, the SLAM language is utilized to model Barscan equipment, Powered Cart Systems, and Automatic Storage and Retrieval Systems. The Computerized Decision Model is also presented. Special attention is given to the identification and measurement of non-model parameters.

Chapter 5 presents the empirical results from implementing the Material Management Algorithm in the case study distribution environment. The final selection alternative from the decision analysis is also provided. The final chapter presents the conclusions and recommendations derived from this research. Specifically, use of the decision support package as a management tool and significant findings of the case study are discussed.
CHAPTER 2
LITERATURE REVIEW

The scope of the problem being addressed requires a multi-topic literature review. Discussions pertaining to simulation model building, language selection, material handling equipment, and Decision Theory are provided. The section on simulation model building is a general review of design considerations and is not intended for the experienced simulation system designer. The section on material handling equipment is provided to isolate alternative methods of material distribution and control that were considered for implementation into the MDC. Selected devices investigated in this research are outlined in the case studies (Sections 2.2.5.1, 2.2.9, 2.2.10.1, 2.2.13).

Lastly, the section on Decision Theory is presented to discuss how the various material handling equipment performance measures, computed in the simulation model, can be simultaneously evaluated and used for final policy selection based on decision maker preferences. The entire section is important because it contains information regarding other efforts at decision support system design, the need for such a development, and the specific orientation of the system design in this research.

2.1 Framework for Simulation Model Building.

This section is provided to highlight important guidelines and considerations in simulation model building. Direct attention is given to the topic of simulation analysis, the scope of model building, and
alternative languages potentially applicable to the research methodology. More detailed perspectives on this material can be found in Murdick [32], Pedgen [33], Schmidt [43], and Shannon [44].

2.1.1 Purpose of Simulation Models.

Concisely stated there are three primary benefit categories of simulation modeling:

1. Improving understanding of existing operations.
2. Solving specific problems related to the system of interest.
3. Predicting future system behavior by introducing changes in the initial work methods [33].

In order to exploit the benefits of simulation analysis careful consideration must be given to model development. The following sections provide important information on defining the boundaries of the problem to be analyzed, model verification, and validation of systems designed.

2.1.2 Elements of Simulation Modeling Framework.

It is important for those interested in simulation design and use to be cognizant of relative environmental boundaries inherent to the system to be analyzed. This perspective will permit a structured approach to defining problems in terms of inputs and outputs.

Shannon [44] identifies six specific elements that characterizes a boundary set or framework for model building:

1. The real system.
2. The conceptual system.
3. The experimental domain.
4. The formal model.

5. The computer implementation or computer model.

6. The experimentation.

While the nature of these elements is relatively straightforward, some further discussion of the first three elements is in order.

The real system is the all important source of potentially acquirable data. The designer may be required to interpret both formal data (documents) and informal data (actual work methods) sources.

Integrating the information gathered from data sources results in the conceptual system as perceived by the designer. This conceptual system is, in fact, the blueprint for design of the specific simulation model.

If one considers elements 1 and 2 as inputs to the simulation modeling effort, element 3, the experimental domain, is identified to organize the model output content. Here, attention is devoted to the specification of goals and the purpose of the study.

An appreciation for the interrelationships of elements 1, 2, and 3 is almost a prerequisite to simulation model building. In fact a step by step procedure for simulation design can be extrapolated from the concepts. Such a procedure is illustrated in Figure 2.1.

2.1.3 The Modeling Steps.

The 12 steps outlined in Figure 2.1 are presented to acknowledge the phases of development in simulation model building. Note that the steps are interrelated, are not always performed in the same sequence, and are dynamic in nature. The aggregate conceptualization is
Figure 2.1. Basic Steps in the Modeling Process [43].
important because successful systems analysis is highly dependent on appropriate design tools inherent to the simulation language chosen. Accordingly, the next section discusses alternative language choices considered for this research.

2.1.4 Simulation Language Review.

This review is provided to briefly overview simulation languages that are currently being used for industrial systems modeling. A general criteria of capabilities is addressed, and lastly the modeling features of two specific languages are examined: SLAM and SIMAN.

The selection criteria for the simulation language used in information systems require the simultaneous fulfillment of the following features:

1. Reduction of the programming task.
2. Provision for conceptual guidance.
3. Ability to define classes of entities within the system.
4. Provide flexibility for change.
5. Provide a means for differentiating between entities of the same class by characteristics attributes or properties.
6. Relate the entities to one another and to their common environment.
7. Adjust the number of entities as conditions vary within the system [44].

While most languages meet this general criteria, some are far more advanced and flexible than others. Knowing in advance what the model will be used for is one sure way to avoid selecting the least capable
language. Within the context of this research and the industrial case study two simulation languages were considered for model design. The attributes of the languages are presented below.

2.1.4.1 SLAM (Simulation Language for Alternative Modeling) [33] [34].

Model building in SLAM (FORTRAN based) can employ discrete, process, continuous, or combined analysis orientations. Note that this material management system application will focus on the process orientation. Continuous change systems can be modeled using differential or difference equations. Discrete orientation in SLAM employs FORTRAN logic and is flow charted accordingly.

2.1.4.1.1 Modeling Procedure.

The process orientation of SLAM employs a network structure consisting of specialized symbols called nodes and branches. These symbols are easily converted into SLAM code.

2.1.4.1.2 Primary Statements.

The primary SLAM statements can be characterized as servers, queues, and decision points. CREATE statements are used to generate entities. Servers are represented in ACTIVITY statements, which represent time duration, or are manipulated individually as RESOURCES. A QUEUE statement is used to queue entities in the network. ASSIGN nodes assign values to entity parameters.

Some of the more elaborate, inherent features of SLAM include delaying entities in queue nodes until a specified condition occurs, file selection capabilities, "resource" modeling, and resource increment changes during the simulation run.
2.1.4.1.3 Computational Features.

SLAM provides the programmer with good statistical analysis capabilities through callable subprograms and random number generators. Some of the accessible distributions include; Uniform, Triangular, Normal, Exponential, Poisson, Erlang, Lognormal, Gamma, Beta, and Weibull.

The ability to manipulate resource levels among server stations is also a feature. This capability facilitates work scheduling as well as traditional service system analysis.

2.1.4.1.4 Output.

The output reports generated by SLAM include: input listing, echo report, trace report and SLAM summary report. The SLAM echo report provides a summary of the simulation model as interpreted by the SLAM processor. Also if an error is detected an error message is printed immediately following the statement where the error occurred. The trace report generates a detailed account of entity processing in the network. The SLAM summary report displays the statistical results from the simulation run [33].

2.1.4.1.5 Applications.

Abbot et al. [1] used SLAM to analyze the operations of a page production department for a large government contractor. Abbot examined four "what if" scenarios including: (1) Additional equipment capacity, (2) Increments in manpower, (3) Increments in transactions, and (4) Redistribution of work assignments. Other applications of SLAM can be found in [33] and [34].
2.1.4.2 SIMAN (SIMulation ANalysis).

SIMAN is a new combined discrete - continuous general purpose simulation language. Its processing capabilities are particularly applicable for modeling manufacturing systems [36].

2.1.4.2.1 Modeling Procedure.

The system to be analyzed is flowcharted using SIMAN symbols (called blocks) that are easily converted into SIMAN code. It is also important to note that a distinction is made between the system model and the experimental frame in SIMAN. "The system model refers to the static and dynamic characteristics of the system. In comparison, the experimental frame defines the experimental conditions under which the model is run to generate specific output data" [36].

2.1.4.2.2 Primary Statements.

SIMAN statements are categorized by function or operation types which include: (1) General function, (2) Resource Function, (3) Material Handling Function, (4) File Function, and (5) Statistics Function. Categories 1, 2, 4, and 5 resemble SLAM commands but provide more flexibility and detail to the programmer. For example, the CREATE block provides the capability to create a batch of similar entities (versus one entity in SLAM) at designated times in the simulation run. Category 3 represents three material handling classes: (1) Industrial Trucks, (2) Cranes, Hoists, and Manipulators, and (3) Conveyors. Examples of the commands associated with these categories are TRANSPORT, ACTIVATE and CONVEY, respectively.
2.1.4.2.3 Computational Features.

SIMAN provides the programmer with very good statistical analysis capabilities through callable subprograms and random number generators. The list of predefined distributions that are accessible include: Erlang, Uniform, Exponential, Triangular, Lognormal, Gamma, Beta, Poisson, and Wiebull [35]. There are also considerable built-in graphical statistical capabilities with SIMAN which will be highlighted under the output section.

2.1.4.2.4 Output.

The SIMAN summary report presents a statistical summary of the simulation run. TRACE capabilities also exist with SIMAN. An additional feature of SIMAN is the built-in graphical presentations of statistical data, called OUTPUT ELEMENTS. These output elements include:

1. PLOT - which generates a plot of time-persistent variables.
2. TABLE - which generates a table of values for observation or time persistent variables.
3. BARCHART
4. HISTOGRAM
5. CORRELOGRAM
6. FILTER - which generates a filtered data set for an observation variable using truncation and batching.
7. INTERVALS - which constructs confidence intervals for observation variables.
2.1.4.2.5 Applications.

Some application experience has been gained in the area of power-and-free overhead monorail systems, minilader storage and retrieval systems and a high volume conveyor line for CRT manufacturing. This analysis was largely conducted at Tektronix, Inc. [36].

Table 2.1 summarizes the respective simulation languages reviewed in this section. As illustrated both languages run on 16 bit microcomputers as well as mainframe computers. This comparison illustrates a slight superiority found in the SIMAN language.

Note however the absence of decision support features among both simulation languages. This void is believed to be an area for potential enhancement and will be fully addressed in later chapters.

2.2 Review of Material Handling Equipment.

The main objective of this section is to examine various material handling systems that might provide enhanced operating standards in a materials distribution center environment. Note that where applicable, special attention is given to those devices considered to be of more immediate interest to the sponsoring firm. In the case of the firm being analyzed, and the decision model input parameters, six fundamental operations are important:

1. Receiving
2. Inspection
3. Movement of Staging Areas
4. Stockroom Storage
Table 2.1
Summary of Features for Simulation Languages

<table>
<thead>
<tr>
<th>Feature</th>
<th>SLAM</th>
<th>SIMAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Procedure</td>
<td>Graphical</td>
<td>Graphical</td>
</tr>
<tr>
<td>Computational Features</td>
<td>Flexible</td>
<td>Very flexible</td>
</tr>
<tr>
<td>Debugging</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>General Use</td>
<td>Any problem type</td>
<td>Any problem type, especially Material Handling Systems</td>
</tr>
<tr>
<td>Extension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Microcomputer Application</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>b) Decision Support</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
5. Retrieval and Order Picking

6. Movement to Mfg. Areas

Following is a discussion of the common attributes found in these operations.

2.2.1 Material Handling Concepts - Time, Motion, Quantity, and Space.

Apple [5] identifies four primary concepts intrinsic to material handling systems: Time, Motion, Quantity, and Space. The interrelationship of these concepts is the focus of this section.

Time has two-fold significance in material handling system considerations. In one respect time refers to the master scheduling of production that is directly related to overall system performance measures such as throughput, responsiveness, and productivity. The second aspect of time pertains to some time-period per item per transport-segment in the distribution network. Minimization of system "throughput time" can often be realized by converting from manual to semiautomatic or automatic systems.

Motion refers to the actual movement of items from destination A to destination B. Material flow is directly influenced by the operations performed on the product. Movement of materials should be to designated areas by the proper handling devices.

Quantity considerations affect unit load sizes and configurations. The characteristics of the materials moved in terms of volume, weight, and mass can be accommodated for in equipment specifications.

Space refers to the capacity of the physical facility to accommodate proposed material handling methods. Factors such as
aisle-space, ceiling height, and both work-in-process and static materials storage areas are key design variables in material handling implementation strategies.

Just as Tompkins [49] called for an integrated approach to facilities planning, one can conclude from the above discussion that material handling system design requires a conscious effort to control the interrelated concepts described to ensure the attainment of favorable system performance levels.

2.2.2 Material Handling Objectives and Control Mechanisms.

Reimink [40] defines material handling control technology as the method or process of directing the movement of goods according to a prescribed plan while maintaining data pertinent to those goods. He further adds that the system must provide equally for the control of equipment and the control of data [40]. It follows that information sources should be identified to retain accurate relevant information to be used to manage and direct the flow of material.

Information sources typically fall into the categories of operator data entry and/or equipment controlled system feedback, both of which have varying degrees of interaction with computers [3]. Computers act as tools in different phases of the project planning horizon. Decision Support Systems, Computer Aided Design Systems, and finally Management Information Systems that actually link production processes, define the typical sequence [20].

Design of a Material Management Decision Support System is the basis of this research. The model will provide decision support by
simultaneously considering the concepts previously outlined and the specific operating characteristics of selected material handling devices. Given that a conceptual framework has been established, a more detailed look at material handling system classification is in order.

2.2.3 Equipment Classification.

Three categories of material handling systems are identified and presented to help show the relationship between the distribution process and the control and speed of material movement per unit time. These three categories are: (1) Mechanized Material Handling, (2) Computer-Aided Mechanization of Material Handling, and (3) Automated Material Handling.

Apple [5] defines mechanization as the process where the human effort is assisted by such equipment as lift trucks and conveyors. These respectively permit higher stacking and increases in the transport speed of materials handled.

Computer aided mechanization refers to devices like bar scanners and computers and radios on fork trucks. This category links manual and mechanized operations with computers, obtaining increased control and tracking of materials.

Automated material handling systems are distinct in that the equipment does the work for the operator(s) and all activity is self regulating and controlled - usually by an on-line computer [5]. Automatic guided vehicle systems and order picking systems fall into this category.
Matson [29] notes that a considerable number of islands of mechanization and automation have evolved in a rush to implement new equipment capabilities. In her review of operational research and material handling it is stated that insufficient time has been devoted to the issues related to the design of integrated systems. Specifically, those who have studied explicit material handling problems have tended to focus on very narrowly defined aspects of the subject: counter examples would include large scale simulation efforts [31].

2.2.4 Storage.

Significant queue lengths discovered as a result of using the simulation model or the desire for more disciplined material storage techniques may require the installation of new storage areas and/or equipment in the distribution center. If necessary, storage racks and mezzines can offer increased capacity to an existing facility.

Apple [5] describes a rack as a framework designed to facilitate the storage of loads usually consisting of upright columns and horizontal members for supporting loads. Storage racks can also be tailored for tilting, sliding, or lift truck drive through. Mezzanines are also frameworks consisting of upright columns and horizontal members, but these are used to support a tier that essentially creates an additional floor in the facility.

A considerable amount of research has been devoted to storage alternatives and space utilization. Kind [31], for example, demonstrated that space should be considered not only at peak but
routine work periods. Matson [31] developed analytical models to determine minimal space design for block stacking that uses deep lane storage. Other examples of related studies can be found in Matson [31].

2.2.5 Forklift Trucks.

Fork trucks are operator carrying, counterbalanced, self propelled, wheeled vehicles, designed to carry loads on forks or other attachments, fastened to a telescoping mask that is mounted ahead of the vehicle to permit lifting, transport, and stacking of loads [5]. Major advantages of the lift truck is that it: (1) can be used to carry a wide variety of attachments to provide an extremely flexible and adaptable handling device, (2) carries its own power source, thus making it useful away from power lines and able to achieve flexible routing paths, and (3) can be used to lift medium to large loads (130k lbs.).

Truck limitations include factors such as: (1) requiring adequate clearances, (2) may be uneconomical for moves over 300 ft., and (3) that material movement efficiency is operator dependent. Important standard calculations on maximum safe loading, aisle width requirements and stacking height requirements are presented in Figures 2.2, 2.3, and 2.4 [24]. Other types include: narrow-aisle trucks, that refer to any one of several types of powered trucks which are capable of operating in a narrow aisle and order picking trucks, that are designed to facilitate the order picking process by making it easier for the operator to control the truck lift while selecting orders [29].
NOTATIONS

\( W \) = Given load, lbs.

\( W_{\text{MAX}} \) = Maximum load weight, lbs. - calculated.

\( L \) = Load length, In. - from manual.

\( A \) = Distance from front wheel axle to heel of fork, in. (drawing).

\( \text{IPR} \) = Inch-pound rating for a given truck (based on std. load), (CW moment).

\( W_0 \) = Rated load capacity, lbs.

\( D \) = Rated load center measured from the heel of the fork, in.

MAXIMUM SAFE LOADING

\[ W_{\text{MAX}} = \frac{2W_0(A + D)}{2A + L}. \]

\( W \) = Less than or equal \( W_{\text{MAX}} \).

\( \text{IPR} = W_0(A + D). \)

Figure 2.2. Maximum Loading on a Counter-Balanced Lift Truck.
NOTATIONS

O  = Pivot point.

R  = Turning radius of truck, in. (given in catalog).

B  = Distance from pivot point ot centerline of truck, in.
     (catalog).

A  = Distance from centerline of front axle to fork heel, in.
     (catalog).

C  = Total clearance on both sides of the aisle, in.

L  = Load Length, in.

W  = Load width, in.

AW  = Aisle width available, in.

AW_{MIN} = Minimum aisle width required, in.

Case I

AW_{MIN} = R + A + L + C

AW  = Greater than or equal AW_{MIN}

Case II

AW_{MIN} = R + \sqrt{(A + L)^2 + (W/2 - B)^2} + C

AW  = Greater than or equal AW_{MIN}

Figure 2.3. Aisle Width Requirements for Right-Angle Turns.
Figure 2.4. Stacking Height (Basis: Wooden Pallet).
Figure 2.4. Stacking Height (Basis: Wooden Pallet).
(Continued)

\( H_{ij}^t \) = Max. lift height of truck \( i, j \).

\( H_{ij}^f \) = Height of fork upright (including backrest) for truck \( i, j \).

\( H^p \) = Height of unit load excluding pallet.

\( = (\text{Height of load/layer}) \times (\text{no. of layers}). \)
\( + (\text{number of layers} - 1) \times (\text{thickness of inserts}). \)

\( t \) = Thickness of top deckboard of pallet.

\( h \) = Pallet height.

\( H^b \) = Clear stacking height of building.

\( d_1 \) = Top clearance required to position topmost unit load.

\( d_2 \) = Bottom clearance required to position topmost unit load.

Remark: Given \( H^b \), select truck type that will maximize cube utilization.

Case 1: \( H^p + t > H_{ij}^f \)

\( H_{ij}^t + H^p + t + d_1 > H^b \)

Case 2: \( H^p + t < H_{ij}^f \)

\( H_{ij}^t + H_{ij}^f + d_1 > H^b \)
2.2.5.1 **Power Driven Carts.**

Powered cart systems are of special interest to the case study management. This equipment includes one power unit pulling loaded carts or trailers. Advantages of the system include: (1) low cost movement of large quantities of material thus providing greater volume in some instances than fork trucks, and (2) the capability to economically travel greater distances than fork trucks. The major limitation is that they require fairly wide aisles for turning corners and maneuvering.

Typical operations for the cart system include use in warehousing operations to collect or deliver loads. The cart concept is certainly a viable alternative to conveyor systems for moderate volume distribution operations. Given the items transported per trailer, associated travel time per destination and equipment cost, the decision model developed will analyze the trade offs of such systems under consideration.

2.2.6 **Conveyor Systems.**

Conveyors are gravity or powered devices commonly used for moving material loads from station-to-station over horizontal, vertical or compound fixed paths [37]. Present operations in the distribution center of the firm being analyzed do not utilize conveyors but the potential for application does exist depending, of course, on the desired throughput rate and specific layout of the departments. Two types of conveyors are flat belt conveyors and roller conveyors.
2.2.6.1 **Flat Belt Conveyors.**

Flat belt conveyors use fabric or metal belts, operating over suitable drive, tailend and bend joints. Materials are placed directly upon the belt. Belt conveyor speeds reach approximately 800 feet per minute and can transport materials over inclines of approximately 28 degrees [48]. The major disadvantages associated with conveyors are high installation costs, fixed path configurations and difficulties encountered in turn maneuvers.

2.2.6.2 **Roller Conveyors.**

Roller conveyors support material loads on a series of rollers, turning on fixed bearings and mounted between side rails. Roller conveyors can be better adjusted for turns presenting advantages for distance routing which may include switches, scales, deflecting equipment, and packaging equipment. Seventy to seven hundred and fifty pounds can be distributed per roller to move materials over 10 degree inclines and 17 degree declines [17]. In general the advantages associated with conveyor use include: (1) relieving manpower of high effort tasks, (2) safer handling and fewer accidents related to manual handling efforts, (3) potential for reduced handling costs, (4) increased production as a result of regulated flow patterns and speeds, and (5) reduced product damage.

High inventory costs of the last decade or so have resulted in a considerable amount of attention to be focused on conveyor theory in comparison to other categories of material handling equipment. There are numerous articles written on the classification and rating of
conveyors in terms of potential application areas and on identifying
general advantages and disadvantages of conveyor types. Some of the
work can be found in Apple [4], Curry [8], and Etheridge [13]. In
addition, Smith [48] devotes considerable attention to determining the
allowable inclines for unit loads on conveyors and to the development
of nomographs that depict horsepower requirements based
on conveyor length and width [46]. Conveyor speed (feet per minute),
weight capacity (ton per hour), and product weight (lbs. per foot),
length and height are the variables used to derive the results.

Using operations research theory, Muth [31] uses differential
equations to develop a deterministic model of material flow on
conveyors having multiple loading and unloading stations equally
spaced. Agee et al. [2] examined the selection of components and
operating specifications for belt, and roller conveyor systems.

While the objectives of these studies seems to have been to
isolate the conveyor and the parameters that make it functional, an
attempt is made in this study to examine the integration of small and
elaborate handling systems in the actual distribution environment under
consideration. The approach is integrated because other key variables
associated with device use such as departmental flow, load and unload
time, and other manual or mechanical tasks can be accounted for and
analyzed. With this end in mind, it was necessary to carefully group
tasks and operations when designing the simulation model so that
minimal recoding is required to make the stated analysis.
2.2.7 Computer Aided Mechanization in Material Handling Equipment.

This section is deliberately separate from the mechanization section to show the potential for time-phased implementation of computers to assist in material management operations. Specifically the characteristics of: (1) radio/computer terminals on trucks, (2) sortation, (3) bar code scanners, and (4) small-parts order picking are examined. Within the context of the firm being analyzed these devices could establish a real time communication link between MDC operations.

2.2.7.1 Computers on Industrial Trucks.

Computer terminals on trucks use highly reliable radio transmission techniques that permit data to be sent from a base station via FM radio signals to trucks equipped with decoding devices and printers [10]. This permits real time, two way communication from virtually anywhere in a plant or warehouse, totally independent of guidewires.

The terminals can be attached to any type of gasoline or electric truck. The power drive to the terminal and radio is supplied by the truck battery. Signals received by a transceiver are decoded by a microprocessor and converted into man readable messages [28]. Information sent from the truck to the base station computer is entered through a terminal keyboard located on the truck. Each base station includes a control computer and a radio transceiver to communicate with the individual trucks.

Duplex signaling is available which allows incoming and outgoing transaction update. Operating ranges of one mile or more can be
achieved using larger overhead antennas [26].

Major benefits derived from the system include giving management the ability to maintain almost constant contact with the operator, improved stock availability (instant knowledge of material location), routine inventory checking, automatic order queueing (operating rules can be built into the software), better batch picking, reduced deadheading, simplified exception handling and an audit trail of each transaction by date and time. Networks can also develop by linking the computer with other stations within the facility [30].

The major disadvantage of the system may be its costs. A $400,000 package includes terminals and communication equipment for five trucks with a cost of about $7000 for additional trucks [10]. The simulation language chosen for the decision model represents lift trucks as resources that are manipulated with various dispatching rules to examine productivity and throughput changes in operations based on those rules.

2.2.8 Sortation Equipment.

Horrey [21] defines material handling sortation as "the act of identifying and inducting products and sorting them to specified destinations." The primary operations involved in sortation of material are as follows:

1. Products must be identifiable by operator or code reader.
2. Products must be inducted into the sortation system.
3. Upon proper identification at checkpoints, information must be sent to the device controlling the sort.
Checkpoint identification by direct source device control uses photoelectric devices and reflectors mounted at different heights prior to each diverter to permit automatic sortation of packages by height or, strips of retroreflective tape can be placed on packages that are coded in a way unique to a given sortation station [21]. Similarly, adjustable signal devices on tote boxes facilitate small parts routing.

Six distinct sorting mechanisms are identified for use depending on the characteristics of the specific distribution system. Each is described below.

2.2.8.1 Deflectors.

Deflectors operate by physically blocking the path of the conveyor. This particular device can attain throughput rates of 20-35 cartons per minute that weigh less than 75 lbs. [21].

2.2.8.2 Diverters.

Diverters or push offs utilize a moving ram or paddle that sweeps moving items from the conveyor surface. Diverters permit throughput rates of approximately 60 cartons per minute for loads up to 100 lbs. [21].

2.2.8.3 Pullers.

Pullers utilize tines that, upon command, pop up from beneath the conveyor surface to stop the load. These tines are also responsible for directing the cartons to the appropriate interface. Pullers are particularly applicable for heavy and durable items [21].
2.2.8.4 **Pop-up Rollers.**

Pop-up rollers are similar to pullers in that cartons are engaged from mechanisms within the conveyor belt area. Throughput rates of 15-20 items per minute for heavier loads are attained through this device [21].

2.2.8.5 **Pop-up Wheels.**

This device uses skewed wheels to achieve sortation. Throughput rates of 80-120 cartons per minute can be sustained on this system [21].

2.2.8.6 **Moving Slat.**

Moving slat sortation also employs skewed wheels in the sortation process. Throughput rates of 100 cartons per minute can be achieved [14].

Although not used in the MDC the sortation devices described above are represented with branching capabilities inherent in the simulation language. Using the branching capabilities and associated activity duration times, alternative paths for material transport can be easily examined.

2.2.9 **Bar Code Scanners.**

As noted previously, one of the primary objectives of any distribution center is to ensure the integrity of the material management function. Maintaining an accurate account of inbound, work-in-process and outbound materials in the most time and labor efficient manner suggested the potential application of bar code scanner devices in the MDC.
Filley [16] assesses bar coding as a way of assigning and recording information about any number of items at one time. He also identifies three elements unique to any bar code reading system. Element 1 is the actual bar code representing data of material description, quantity, vendor, and purchase order number, internal destination, etc. Element 2 is the bar code scanner or sensing device. The scanner reads an analog code attached to materials, decodes the information and transmits a digital signal to a host computer. The bar code decoding device is the third element of the system.

Scanners are of four distinct types:

1. Hand Held Fixed Beam (wands or light pens) - must come in close contact with the bar code to read it.
2. Hand Held Moving Beam (gun) - is operated by shooting a beam of light over the bar code.
3. Stationary Fixed Beam - reads the bar code as it passes through the scanners precise field of view.
4. Stationary Moving Beam - reads the bar code by shooting a beam of light over the bar code [16].

Other operating characteristics of the bar code and scanning system include:

1. Weight (17.7 oz. to 10 lb.)
2. Memory (0 - 256k)
3. Number of transactions before recharging (8 hr. - 100k transactions)
4. Price ($600 - $3700) [15].
Generally moving beams are considered superior to fixed beams because the speed of reading is not operator dependent. And non-contact scanners are also considered superior because they do not actually touch and create wear on the codes [16].

In the case of the firm being analyzed, the bar coding/scanner concept is particularly viable because of its potential for application in manual, conveyor or automated environments. Another consideration relating to adaptation is the potential to relocate or decentralize inbound inspection procedures. In order to accommodate bar code concepts in the simulation model processing times were obtained and incorporated in the appropriate network interfaces.

2.2.10 Small Parts Order Picking Systems.

In the case of the firm being analyzed a significant proportion of items requiring stockroom storage are small parts. Because the current operations are labor intensive, computer-aided picking systems are examined that may be more efficient and cost effective in the stockroom department.

Order-picking equipment can be broken down into two categories: (1) man-to-part systems and (2) part-to-man systems. Each is described below.

1. Man-to-Part Systems.

Walk-and-Pick systems require the operator to walk to the appropriate storage location, retrieve/stock orders and return to the workstation. Many problems are associated with this method and include:
1. A considerable amount of walking and searching is required of the operator.
2. Too often, stooping and bending is required to obtain parts.
3. Overall time consuming efforts and lack of control of the system [30].

Also included in the man-to-part system are order-picker fork trucks (discussed in previous section) and man-ride machines or man-aboard crane systems.

2. **Part-to-Man Systems.**

Part-to-Man systems employ the use of equipment to deliver materials to the operator's particular workstation. Two such systems include the carousel loop and the mini-load crane.

2.2.10.1 **Carousel.**

The carousel loop consists of a series of rotating bins driven by a motor and chain in a narrow loop configuration [23]. Advantages associated with the use of carousel loops include the following:

1. Reduction of aisle space between storage loops.
2. Ability to increase storage capacity with multiple tier loop/mezzanine configurations.
3. Enhanced kitting operations due to multiple tray availability.
4. Potential to integrate into fully automated system.
5. Potential for reduced manpower requirements [23].

Disadvantages of carousel loop systems related to equipment reliability considerations. Beyond this constraint, however, carousel systems offer legitimate methods for productivity enhancement in
stockroom environments possessing the stated characteristics. Carousel equipment is investigated in the MDC stockroom operations for issue transaction processing. (See Table 2.1 for summary of Picking System Characteristics.)

The final category of material handling systems examined in this review are totally automated. This level of material management and distribution utilizes integrated computer controls for real time analysis capabilities. Specifically automatic guided vehicle systems and automatic storage and retrieval systems are examined.

2.2.11 Automatic Guided Vehicle Systems.

Automatic Guided Vehicle Systems (AGVS) utilize unmanned, electronically guided vehicles, generally under the control of a base computer, that can automatically perform unit-load pick-up and delivery activities and seek various paths in the facility. AVGS can be classified as one-way or two-way systems. The advantage of one-way systems are simplicity of control while its major weaknesses are: (1) that longer traveling distances may be required to reach the required destinations, and (2) that a faster vehicle may be blocked by the slower moving vehicle ahead of it. In addition to the travel car the fundamental components of any AGVS include: (1) arcs, which are guideway segments, and (2) nodes, (or intersections) that are points in the system were two or more segments of guidewire meet. Conflict nodes are those that serve as terminal nodes to two or more arcs [17].

Egbelu et al. [13] identifies two vehicle task assignment problems that affect productivity. The first problem arises when the
Table 2.2. Picking System Characteristics*.  

<table>
<thead>
<tr>
<th>Travel Speeds</th>
<th>Throughput Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man-Rider Crane</td>
<td>60 picks or move/hr. + man-to part system</td>
</tr>
<tr>
<td>300 ft. per min. (FPM)</td>
<td></td>
</tr>
<tr>
<td>Mini Load Crane</td>
<td>Below 60 picks/hr. + part-to-man system</td>
</tr>
<tr>
<td>300 FPM</td>
<td></td>
</tr>
<tr>
<td>Lift Trucks</td>
<td>Storage Compartment</td>
</tr>
<tr>
<td>170 FPM</td>
<td>Depth and Width</td>
</tr>
<tr>
<td>Carousel</td>
<td></td>
</tr>
<tr>
<td>80 FPM</td>
<td>Equipment</td>
</tr>
<tr>
<td></td>
<td>Depth into</td>
</tr>
<tr>
<td></td>
<td>Man-Rider Cranes</td>
</tr>
<tr>
<td></td>
<td>mini-load crane 4 ft. 2 ft.</td>
</tr>
</tbody>
</table>
|                        | Order Picking Fork Trucks 50-200 ft.  
|                        | man rider crane 1½ ft. 3 ft.                           |
|                        | Mini-load Cranes                                          |
|                        | fork lift 4 ft. 4 ft.                                    |
|                        | Carousel Loops 20-100 ft.  
|                        | carousel 1½ ft. 2 ft.                                    |

Typical Aisle Lengths

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Depth into Shelf</th>
<th>Width Down Aisle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man-Rider Cranes</td>
<td>100-400 ft.</td>
<td>mini-load crane</td>
</tr>
</tbody>
</table>
| Order Picking Fork Trucks | 50-200 ft.  
|                       | man rider crane |
| Mini-load Cranes      | 50-100 ft.       | fork lift 4 ft.  |
| Carousel Loops        | 20-100 ft.       | carousel 1½ ft.  |

Inside Clearance (floor to lowest point in ceiling)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Depth</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranes</td>
<td>20-40 ft.</td>
<td></td>
</tr>
<tr>
<td>Trucks</td>
<td>30 ft.</td>
<td></td>
</tr>
<tr>
<td>Carousels</td>
<td>12 ft.</td>
<td></td>
</tr>
</tbody>
</table>

Length of Area (Runout)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranes</td>
<td>10 ft.</td>
</tr>
<tr>
<td>Trucks</td>
<td>12 ft.</td>
</tr>
<tr>
<td>Carousels</td>
<td>3 ft.</td>
</tr>
</tbody>
</table>

Width of System

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranes</td>
<td>13 ft.</td>
</tr>
<tr>
<td>Lift Truck</td>
<td>13 ft.</td>
</tr>
<tr>
<td>Man rider</td>
<td>7 ft.</td>
</tr>
<tr>
<td>Carousel</td>
<td>11 ft.</td>
</tr>
</tbody>
</table>

*Note: FPM stands for Feet per Minute.
Table 2.1 (Continued)

<table>
<thead>
<tr>
<th>Maximum Weight in Items to be Stored</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranes</td>
<td>500-1000 lbs.</td>
</tr>
<tr>
<td>Trucks</td>
<td>2000-3000 lbs.</td>
</tr>
<tr>
<td>Carousel</td>
<td>650 lbs.</td>
</tr>
</tbody>
</table>

*[24]*
selection of a vehicle is to be made from a set of unassigned vehicles to service a work center requesting a free vehicle. The second independent problem arises when a vehicle has been released and is to be reassigned to another task, in this instance, essentially one is forced to prioritize workcenters and implement dispatching rules accordingly [13].

Several heuristic rules are introduced corresponding to work center generated and vehicle utilization considerations.

Workcenter generated rules include:
1. Random vehicle selection rule.
2. Shortest travel time selection rule.
3. Longest travel time selection rule.
4. Longest idle vehicle selection rule.
5. Least utilized vehicle selection rule [13].

Similarly vehicle generated assignment rules include:
1. Random work center selection.
2. Work center having the nearest pickup point relative to the released vehicle.
3. Work center having the furthest pick up point.
4. Work center having the largest number of outbound unit loads in the queue.
5. Work center having the minimum remaining positions for additional unit loads in the outgoing queue.
6. Sequential work center selection rule.
7. Unit load shop entry time dependent rule [12].
Aside from research relating to dispatching rules Quinan [36] lists nine points on justifying an AGVS system, briefly they refer to:

1. More than 5% material misplaced by manual methods.
2. Having 10 or more deposit-pickup locations in the facility.
3. Total activity between these locations exceeding 35 loads an hr.
4. Labor savings trade-off in converting from manual system.
5. Converting from conveyors of 300 ft. or more and economic and space savings.
6. On-line feedback capabilities.
7. Material movement that must automatically interface with ASRS or other automatic equipment.
8. Precise handling capabilities achievable with AGVS [38].

The information provided above is presented to assist in the long range planning considerations of the firm being analyzed. That is, upon detailed examination of the Kitting and Packaging Departments, material management and distribution requirements.

The simulation model network developed here should act as the framework for the AGVS because the boundaries separating the departments in the model constitute the aisles on which the vehicle guidewpath systems are laid. Another major advantage of the simulation model is that the simulation language (SLAM) used has the capability to test the various dispatching/selection rules that are discussed above.

2.2.12 Automatic Storage and Retrieval Systems.

Fully Automated Storage and Retrieval Systems (ASRS) are
individual or groups of material handling equipment that can automatically put to stock or retrieve materials. Some systems consist of stacker canes while others combine robotic/carousel configurations to handle materials. ASRS are not contingent upon syncranised use of AGVS but the latter is enhanced by some form of the former when attempting to totally integrate operations in the distribution process.

General requirements of most ASRS include:

1. Unit loads of fixed size.
2. The ability to stack products on pallets.
3. The ability to place small components in special containers.

The advantages of ASRS in terms of productivity increase include the following:

1. Reduced material handling manpower.
2. Reduced product damage.
3. More accurate inventory control.
4. Reduced heating and lighting.
5. Reduce storage requirements due to random storage.
6. Higher throughput rates [23].

The simulation model directly examines this device as an extension of carousel operating capabilities. In both cases determination of processing durations is fully explained. Also, the simulation model can directly aid in the analysis of robot/ASRS systems because of its capability to simulate discrete event task functions.
2.2.13 Case Studies.

The following case studies are presented to illustrate the actual industrial application of the equipment discussed above. Of particular significance, are the combined configurations of the material handling equipment and the documentation of improved productivity measures for the respective firms. Specifically the case studies include illustrations of:

3. Robot and Carousel Inventory Handling.

2.2.13.1 Bar Code Scanners.

The El Greco Leather Products Co., Inc., of Port Washington, N.Y. coordinates the movement of approximately 5000 cartons of shoes per day through its distribution center. Minicomputers control scanners and sortation devices located on conveyors. Hand-held laser scanners are used in the receiving area to eliminate time consuming repetitive handling of in-bound materials. Scanners are also used to double check materials that are scheduled for shipping outside the distribution center. By receiving cartons with pre-specified bar-code labels the time to update inventory records has been reduced from two days to one hour and shipment accuracy has been increased to virtually 100% [30].

2.2.13.2 Power Driven Cart Systems.

Power driven cart systems have recently been adopted by IBM, Charlotte, N.C. In this particular system materials are stored and transported between workcenters in roller carts. As many as 3 to 4
carts are transported simultaneously, depending upon the destination. While specific figures on improved operating standards are not available the general productivity improvement over traditional fork truck use was estimated at 50%. The cart system was also stated to be considerably more flexible and cost efficient than conveyors.

2.2.13.3 Robot and Carousel Inventory Handling.

The IBM, Boca Raton, Florida manufacturing plant produces card components for installation on multiple product line circuit boards. Cards are routed to several workstations in the facility. Performance measures for the system design included:

2. Location of materials.
3. Priorization of work in process items to ensure smooth work flow [24].

Several material handling configurations were analyzed and subsequently a combination, of tilted rack central storage, conveyor, bar code/scanner, carousel, robot, and AVGS are adapted. CARTS (Carousel Robot Transport System) is the acronym used to officially describe the configuration.

This section of literature review has focused on material handling equipment that offers the potential for improving operating standards in a materials distribution center environment. The material handling equipment is categorized as mechanized, computer-aided, or fully-automated to distinguish between the rate of material flow and real-time control derived from the system. The fundamental concepts of
time, motion, quantity, and space were also introduced to provide a conceptual framework of material handling design parameters.

The ability of the simulation model to incorporate the equipment capabilities will be of major concern in the research. A detailed analysis of selected alternative configurations is examined in the context of the case study in latter chapters.

2.3 Review of Decision Theory.

Successful design of the Material Management Decision Support system will be complete when the capability to evaluate simulation model performance measures and non-model parameters, such as costs, in a collective manner is provided to the user. "Successful design" refers to system architecture that will address the following considerations:

1. Assisting in the evaluation of alternative plans and courses of action.
2. Assisting in the avoidance of information processing biases and poor judgemental heuristics.
3. Assisting in the proper aggregation of information cues from multiple distributed sources [41].

To accomplish this objective a decision model was sought to meet the following criteria:

1. Quantitative in nature.
2. Intuitive in nature.
3. Applicable to the materials distribution environment (flexible).
4. Reliable selection response.
Towards this end, the following section of the literature review will focus on Decision Theory.

2.3.1 Categorization of Decision Rules.

Decision rules are utilized when there exists: (1) a set of alternatives, (2) information regarding the performance of these alternatives and (3) associated preference information. Three general categories of Decision Rules can be examined: (1) Holistic, (2) Heuristic, and (3) Wholistic.

1. Holistic decision rules involve evaluation and preference weighing of several alternatives. A comparison of all alternatives is made and the alternative with the highest aggregated weight factor is chosen as most consistent with user preference.

2. Heuristic decision rules provide aid or direction in the selection of alternatives but are otherwise less quantitative in nature than holistics. These are commonly referred to as "rules of thumb".

3. Wholistic decision rules select alternatives based upon user expertise rather than detailed conscious consideration of the individual aspects of alternatives [42].

Evidence suggests that individuals are generally incapable of assimilating and integrating a large number of variables in a single judgement task [11]. Therefore, efforts to interface decision support capabilities with the simulation model will focus on holistic evaluation.
Specifically holistic constructs can be used to evaluate an alternative over several criteria. Such a preference evaluation then represents a single criteria upon which to compare alternatives. This is the basic premise of utility theory.

2.3.2 Value-Functions Definition.

Utility theory investigates whether preferences can be represented in numerical fashion. If it is possible to do so, there is a mapping from a set of alternatives into a subset of real numbers such that between any two alternatives the one which is preferred is assigned a larger number. This mapping is referred to as utility or value function. Further, the general expression used to represent these value functions is found in conjoint measurement theory.

2.3.3 Multiattribute Preference Modeling.

Conjoint measurement theory can be used to analyze riskless multiattribute decision making. The following expression represents an additively decomposed value function:

\[ F(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} w'_i x_i \]

where \( x_i \) denotes the state of the outcome \( X = (x_1, x_2, \ldots, x_n) \) in the \( i \)th attribute, \( w'_i \) is the preference weight of the \( i \)th attribute, and \( F \) is composite additive value function that maintains the decision makers preference ordering among alternatives.

2.3.4 The Modeling Strategy.

Conjoint measurement decomposition models initially structure the decision problem by determining the basic dimension of importance. Following this, the evaluation task is broken down into the evaluation
of individual attributes over individual alternatives and differential weights (within the dimension of importance) are attached to these attributes. Weights are then aggregated using additive models. Aside from their intuitive properties, these models are generally justified by their robustness against minor violations in individual applications. Articles which support the assertion that additive models provide results consistent with intuitive judgement are given by Dawes [9], Fischer [18] and more recently by Sage [42].

2.3.5 The Technology of Utility Assessment.

Once the form of a utility model has been ascertained the critical issue becomes one of selecting or developing an assessment technique with desirable properties from an implementation standpoint. Several procedures are available for assessing parameter values in preference modeling. This section will present some of these methods and discuss cases for which the various types of assessment methods are appropriate.

2.3.6 Approaches to Utility Assessment.

Generally speaking, there are five mutually exclusive broad categories of assessment techniques for measuring utilities. These include: (1) ranking, (2) category methods, (3) direct methods, (4) gamble methods, and (5) indifference methods.

2.3.6.1 Ranking Methods.

This is the simplest of the five techniques and requires only that the decision maker order the attributes from the most preferred to the least, or choose the most preferred attribute in a paired comparison
procedure. As previously discussed, ranking of attributes is typically used as a first step to structure an assessment, after which another technique is used to obtain numerical utility values. Since ranking is the type of judgement that is common to everyday thinking, these methods have appeal to many decision makers. Theoretical considerations pertinent to ranking methods are discussed in Thurstone [50].

2.3.6.2 Category Methods.

Category or interval methods involve classifying the worth of levels of a parameter into a fixed number of discrete categories. Although the method yields sufficient information for some models, only approximate numerical worths can be determined with the method. Theoretical considerations pertinent to category methods are discussed in Thurstone [50].

2.3.6.3 Direct Methods.

Direct methods assign numerical worths directly to attributes or levels of attributes. Direct methods have appeal due to their ease and speed of application. The methods can be grouped into two major variations. In one case, the most frequently used variant anchors the extreme attribute levels at the extremes of the worth scale. In the other case, a single anchor point is used, with each attribute level being compared to this point. Essentially, the decision maker is asked to give a number which represents the ratio of the utilities rather than an interval level judgement as between two extreme points.
2.3.6.4 **Gamble Methods.**

Gamble methods involve the construction of wagers where attribute levels or combinations are varied and probabilities adjusted until the decision maker is indifferent between the wager and an alternative sure thing. A wager is defined as a situation where each one of a set of outcomes can occur with a given probability. These methods rely on the decision maker's ability to make consistent choices between risky alternatives, and are the only assessment techniques which have a well developed theoretical basis [51]. They are also the only methods which allow and impose explicit assessment of risk and uncertainty. As a result, they are appropriate for assessing utilities in situations that involve risk, but are inappropriate for riskless decision situations. Application of gamble methods tends to be cumbersome and some processing of results is required to generate utility functions. A detailed treatment of the methods is given in Raiffa [39].

2.3.6.5 **Indifference Methods.**

Indifference methods involve the joint assessment of two attributes by constructing a plane of the possible combinations of the levels of two alternatives and then determining indifference points and curves on the plane. Indifference methods are based on having the decision maker judge the trade-off between the utilities of various factor levels.

Specifically, the decision maker may be asked; to indicate the attribute levels at which he would be indifferent between sets of attribute combinations, or to indicate the attribute levels at which he
would be indifferent between two attribute combinations. Indifference methods are particularly appropriate for non-independent attribute analysis.

2.3.7 **Summary of Implementation Results.**

Because ranking and category methods provide only weakly ordered sets of alternatives, they cannot be employed to estimate numerical value and utility functions [17].

Consequently selection of an appropriate assessment procedure should be confined to direct, indifference, or gamble methods. However, results from tests applications indicate that direct methods are dominant unless there are dependent factors or uncertainty that must be formally considered in the assessments [17]. Suggestion of this dominance results from the points that:

1. Direct methods generate numerical worths, have high face validity and are easy to apply.
2. Direct methods are integral to many frequently used methods of utility assessment.
3. Assessments made using direct methods appear to be highly comparable to assessments that involve uncertainty.
4. Direct methods are frequently used in conjunction with ranking methods to establish a preliminary utility scale.

A more detailed comparison of utility assessment techniques is provided in Table 2.2. Following, a more detailed description of direct assessment methods is provided.
Table 2.3. Comparison of Utility Assessment Techniques [22].

<table>
<thead>
<tr>
<th></th>
<th>Ranking/Cat. Methods</th>
<th>Direct Methods</th>
<th>Gamble Methods</th>
<th>Indifference Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Factors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk/Uncertainty</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Continuous/Discrete</td>
<td>Discrete</td>
<td>Either</td>
<td>Either</td>
<td>Continuous</td>
</tr>
<tr>
<td>Independence Required</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Montonicity Required</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Decision Maker(s)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Response required</td>
<td>Pref/Cat.</td>
<td>Quantitative</td>
<td>Indifference</td>
<td>Indifference</td>
</tr>
<tr>
<td>(judgment types)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task Complexity</td>
<td>Very Simple</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Simple</td>
</tr>
<tr>
<td>Training required</td>
<td>Almost none</td>
<td>Moderate</td>
<td>Extensive</td>
<td>Little</td>
</tr>
<tr>
<td>Acceptability</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Generally Low</td>
</tr>
<tr>
<td>Face Validity</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Assessment Time</td>
<td>Quick</td>
<td>Moderate</td>
<td>Slow</td>
<td>Slow</td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Processing</td>
<td>Little</td>
<td>Usually</td>
<td>Moderate</td>
<td>Moderate to High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>none</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>Relative Worth</td>
<td>Num. Worth</td>
<td>Num. Worth</td>
<td>Rel./Num. Worth</td>
</tr>
<tr>
<td>Response reliability</td>
<td>High (if few attrib.)</td>
<td>Moderate/High</td>
<td>Moderate</td>
<td>Moderate/Low</td>
</tr>
<tr>
<td><strong>General</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyst skill req.</td>
<td>Little</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Flexibility</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
2.3.8 Direct Assessment Procedures.

Of the many direct assessment procedures summarized by Fishburn [17], the majority involve judgments for which utility models provide no basis. Despite this, Fischer [18] cites a high degree of convergence across scaling techniques, and suggests that other assessment techniques ought to provide excellent approximations to the theoretically feasible methods. Among these other methods, (summarized in Table 2.3.), a method utilizing a procedure of successive comparisons based on Churchman and Ackoff [7] is representative of direct assessment procedures applicable to discrete alternative problems.

The method in [7] involves two variations of a procedure for estimating the importance of alternatives on a scale of value. It should be emphasized that the method pre-supposes each of the assumptions underlying the development of riskless multiattribute models, and seeks to develop weights for attribute values. Extension of the method to risky choice situations is trivial, and accomplished by associating a probability measure with each event in an additive value function.

The simplest version of the Churchman-Ackoff procedure can be summarized in six discrete steps which include [adapted from 7];

Step 1: Rank the attributes in their perceived order of value. Let $A_1$ represent the most valued, $A_2$ the next most important, ... and $A_n$ the least important.

Step 2: Assign the value 1.00 to $A_1$ (i.e., $w_1 = 1.0$) and assign values that appear suitable to each of the other outcomes.
Table 2.4. Alternative Utility Assessment Methods.

<table>
<thead>
<tr>
<th>Methods*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ranking**</td>
</tr>
<tr>
<td>2. Direct Rating**</td>
</tr>
<tr>
<td>3. Standard Gambler</td>
</tr>
<tr>
<td>4. Direct Midpoint Bisection</td>
</tr>
<tr>
<td>5. Probabilistic Midpoint</td>
</tr>
<tr>
<td>6. Direct Ordered Metric**</td>
</tr>
<tr>
<td>7. Probabilistic Ordered Metric**</td>
</tr>
<tr>
<td>8. Probabilistic Rating</td>
</tr>
<tr>
<td>9. Successive Comparison</td>
</tr>
<tr>
<td>10. Half-Value Sum</td>
</tr>
<tr>
<td>11. Ordered Metric</td>
</tr>
<tr>
<td>12. Single Trade-Off</td>
</tr>
<tr>
<td>13. Double Trade-Off</td>
</tr>
<tr>
<td>14. Single Transformation</td>
</tr>
<tr>
<td>15. Double Transformation</td>
</tr>
<tr>
<td>16. Discrete Trade-Off</td>
</tr>
<tr>
<td>17. Discrete Transformation</td>
</tr>
<tr>
<td>18. Discrete Adjacency</td>
</tr>
<tr>
<td>19. Saw-Tooth</td>
</tr>
</tbody>
</table>

*See Fishburn [17] for references on each method.

**Uniform and variable scale range approaches available.
Step 3: Compare $A_1$ versus $A_2 + A_3 + ... + A_n$ (where $+$ indicated the logical connective "and").

(3.1) If $A_1$ is of greater importance than $A_2 + ... + A_n$, adjust the values of $w_1$ such that $w_1 > w_2 + ... + w_n$. Proceed to Step 4.

(3.2) If $A_1$ is equally important as $A_2 + ... + A_n$, adjust the values of $w_1$ such that $w_1 = w_2 + ... + w_n$. Proceed to Step 4.

(3.3) If $A_1$ is less important than $A_2 + ... + A_n$, adjust the values of $w_1$ such that $w_1 < w_2 + ... + w_n$.

(3.3.1) Compare $A_1$ versus $A_2 + A_3 + ... + A_{n-1}$.

(3.3.1.1.) If $A_1$ is more important, adjust the values so that $w_1 > w_2 + ... + w_{n-1}$. Proceed to Step 4.

(3.3.1.2.) If $A_1$ is equally important to $A_2 + ... + A_{n-1}$, adjust the values so that $w_1 = w_2 + ... + w_{n-1}$. Proceed to Step 4.

(3.3.1.3.) If $A_1$ is less important than $A_2 + ... + A_{n-1}$, adjust the values so that $w_1 < w_2 + ... + w_{n-1}$.

(3.3.1.3.1.) Compare $A_1$ versus $A_2 + A_3 + ... + A_{n-2}$ and so on until either $A_1$ is preferred to the rest, then proceed to Step 4, or until the comparison of $A_1$ versus $A_2 + A_3$ is completed, then proceed to Step 4.

Step 4: Compare $A_2$ and $A_3 + A_4 + ... + A_n$ and proceed as in Step 3 above.

Step 5: Continue until the comparison of $A_{n-2}$ versus $A_{n-1} + A_n$ is completed.
Step 6: Convert each \( w_i \) into a standard value \( w'_i \), dividing it by 
\[
\sum_{j=1}^{n} w_j \text{ so that } \sum_{j=1}^{n} w'_j = 1.
\]

The weights generated for attributes using this method would be used in an additive or multiplicative utility representation to assign a total weight (utility) to alternatives over the set of relevant attributes.

2.3.9 Applications of Decision Support System Concepts.

Several studies have addressed the design and use issues of a decision support system. Ideally, this should involve the aggregation of key parameters among alternatives in a way that reduces the complexity of the decision-making selection process.

Rouse [41], for example, developed a decision analytic approach to quantifying the tradeoff between the U.S. Army Corps of Engineers (USACE) response time (in wartime) and permanent staffing levels (in peacetime). This approach, however, was not computer based.

More recently Smith et al. [46] detailed a micro-computer based decision support system for engineering economic project evaluation. His work is particulary good because some detail is devoted to identifying the interrelationships and interfaces among DSS components. Specifically the decision maker, model base and data base are the primary elements of his analysis. However, close examination of the model base reveals that its function is to only manage the data base structures, indeed providing more information to the user but not aggregating key parameters among alternatives. Therefore, in a strict sense, referral to the design as decision support is a misnomer, whereas management information system may be more appropriate.
In this section the various techniques available for the assessment of utility functions have been reviewed. It is shown that the choice of an appropriate assessment technique should be guided by the form of the utility model and therefore by the assumptions defining the decision problem. In reference to the design of the tool for planning and decision support, the essentials of step 3 (interpretation of issue) have been collected.

This research focuses on the direct assessment method because of its capability to systematically evaluate factors in the material management system that are not reducable to cash flows and the response reliability associated with the technique. An example of the interfacing of the simulation model and the assessment model is given in Chapter 3.
CHAPTER 3
THE MODELING APPROACH

This chapter outlines the methodological framework of a model based Material Management Decision Support System. The primary subject matter addressed includes:

2. An overview on the determination of system performance measures used in the research.
3. The introduction of a formal algorithm which establishes an interface between simulation output analysis and computerized decision support for the purpose of final policy selection among some set of Material Handling equipment alternatives.

3.1 Framework for a Decision Support System.

Figure 3.1 illustrates the conceptual framework for a Material Management Decision Support System. As noted earlier, the acquisition and transformation of data into usable form are the essential steps for model design. The resulting simulation model gives the user the capability to investigate relationships between variables in the material distribution network. Specifically these include policy alternatives such as priority work scheduling and/or workcenter responsiveness to automation. This systematic approach to policy analysis gives the user the necessary understanding of operations required to meet service demands from other departments in the production cycle.
Figure 3.1. Conceptual Framework for Decision Support System.
Given that a thorough job of analysis is conducted, the sequence of events leading to some adopted course of action is still incomplete. In fact, usually there is some set of alternatives that must be evaluated based on their respective attributes. For example, the output analysis from the simulation model will contain statistics on several system performance measures, such as; utilization, throughput, responsiveness, and capacity. These performance measures along with other parameters, not calculated directly in the simulation, make up an extensive list of potential decision criteria.

The development of a computerized Decision Support Model in this research is motivated by the postulate that decision makers often perform poorly in aggregating a large number of information cues and consequently biases are introduced in the evaluation and selection of alternatives. However, the Decision Support Model gives decision makers the capability to express their preferences for attributes systematically, reduce costly biases, and essentially establish a common criteria by which all policy alternatives are measured.

With this end in mind, a concise method of analyzing policy alternatives involving material handling equipment is demonstrated. The investigation of this equipment is based on the literature cited in Chapter 2 of this research. As stated, the emphasis in some areas of handling devices is due to the specific requirements of the industrial case study.
3.2 **The Case Study.**

The material management operations of a large government contractor are used as a case study to test the practical applicability of the research. A 49,000 square foot Materials Distribution Center (MDC) provided the warehousing and material management operations that are typical of industrial material distribution systems. The MDC is describable as a network of workcenters that perform services on incoming materials. Identification of materials, inspection, movement, storage and retrieval operations are the primary responsibilities of the distribution center.

A computerized simulation model of these operations gives management the capability to analyze alternative manual, semi-automatic, and automatic work methods in the distribution process and complete the essentials of step 1 and 2 in the design of the Decision Support System.

3.3 **Simulation Language Choice.**

SLAM (Simulation Language for Alternative Modeling) developed by Pritsker and Pegdon [2], was immediately available to the sponsoring firm and therefore adopted to model the MDC system. A brief discussion concerning the benefits derived from using SLAM is provided below but it is also important to note that an equally sufficient alternative exists to modeling the operations with SIMAN.

The MDC facility is representative of a network system where entities representing arrivals of incoming materials flow from one node
to another, and where nodes represent workstations. The process orientation of SLAM is used to formulate a network model reflecting the important characteristics of the MDC operations and to provide a management tool for policy analysis.

The movement of materials and their processing at workcenters suggests that the MDC can be modeled as a complex queueing system. The SLAM processor will compute important statistics on such queues as well as on count, time, and utilization performance measures. The count mechanism will account for all entities flowing within the system, indicate the level and pattern of flow and system production capacity. Queue statistics from the report provide information on bottlenecks in the system that require workload balancing. Time statistics provide information on the time entities spend between specific nodes which are used to indicate the effects of labor and equipment reallocation on system throughput measures. Finally, the utilization statistics provides information regarding server/resource utilization.

In summary, SLAM is considered an effective simulation language for this case study due to its relative simplicity and flexibility in model building, and its well structured statistical analysis information contained in the SLAM summary report. The logic of the model for simulating the MDC operations can be used in many similar systems. This is because the MDC is representative of a large class of internal material distribution centers encountered in industry.
3.4 Phased Development of the MDC Simulation Model.

It should be noted that the initial coding of the MDC model was developed in two phases due to the nature of the case study. Phase one examined the existing operations of material receipts through the routing of materials awaiting stockroom processing. This author's contribution to phase one involved on-site data collection that acted as input to the coding effort. The phase one portion is presented here so that alternative material handling equipment can be analyzed throughout the distribution facility. Phase two modeling efforts focus on analysis of the MDC Stockroom operations. The major transactions captured in the model include external receipts, internal credits, and issues. The linkage of the models will, as requested by the firm, describe the primary relationships that determine the behavior of the materials distribution system in the MDC.

In the subsections that follow, a detailed description of the Stockroom simulation model is presented. The discussion will be particularly pertinent to the design analyst because of the analysis flexibility built directly into the model.

Section 3.5 provides a detailed conceptual description of the operations and workflow in the MDC. The purpose of the description is to define the boundaries, components, and process interactions that determine the behavior of the material management system.

3.5 Description of MDC Operations.

The Materials Distribution Center (MDC) at IBM-FSD, Manassas, Virginia, is described by Flow Diagrams A, B, C, D, and E in Figures
3.2, 3.3, 3.4, 3.5, and 3.6, respectively. Diagram A depicts the flow of items arriving to the MDC and the processing between arrival and final placement to stock. Diagram B depicts the detailed flow of materials in the Document Control Department. Diagram C depicts the detailed operations of the Receiving and Inspection Department. Diagram D depicts the detailed flow of materials in the Stockroom Department. Diagram E depicts the workflow of exception materials and the primary responsibilities of the stockroom clerk. The diagrams contain nodes \((\square)\) that represent departments or holding areas in the MDC while branches \((\rightarrow)\) represent material movement and processing operations for deliveries. The subscripts, \(n\), contained inside the nodes \((\square n)\) correspond to particular activities within the respective departments and are used to guide the reader through the network.

Upon arrival deliveries are received and unloaded by receiving dock operators (Diagram A - node 1&2). The operators manually inspect containers (boxes, etc.) for category classification, and arrivals are handled in one of four ways:

1. A container is classified as chemical and moved to a separate facility to await processing outside the network.
2. A container is classified as Bulk, palletized and moved to the Bulk Staging area by hand lift or fork-lift truck.
3. A container is classified as UPS and manually transported to the UPS Staging area.
4. A container is classified as Big-Bulk, processed on the dock in a designated area and routed outside the network.
Figure 3.2. Diagram A. Flow Diagram of Receiving Operations.
Figure 3.3. Diagram B. Flow Diagram of Document Control Operations.
MDC FLOW DIAGRAM C
Receiving/Inspection

Key:
Material Flow - solid line
Document Flow - dashed line

Figure 3.4. Diagram C. Flow Diagram of Receiving/Inspection Department Operations.
Figure 3.5. Diagram D. Flow Diagram of Primary Stockroom Department Operations.
Figure 3.6. Diagram F. Flow Diagram of Clerk Operations.
At this point only Bulk and UPS materials remain in the network and their routing is continued.

Following delivery to the staging areas both UPS and Bulk items must be unpacked for detail identification, logged into the materials control system and moved according to routing instructions. A detailed description of these operations, including document control area processing of arrivals, follows.

Deliveries to the Bulk/UPS staging area are unpacked by Bulk/UPS holding area operators who collect the necessary packing slips and routings. The operator palletizes/manually transports the particular physical item to the Bulk/UPS holding area where the delivery remains until united with a Manufacturing Order Control card (MOC) (Diagram A - node 6-9). Packing slips must be submitted to the Document Control Area where the material control system is updated by purchase order number (subsequent to transport the stockroom operator must walk to and from this area).

Diagram B describes the Document Control Area. Purchase Order (P.O.) and Part Service Transmittal (PST) Forms are processed in this area on a first-come-first-serve basis. Three possibilities can occur with paperwork within the Document Control Area:

1. System data for an order is correct, the item is received and an MOC card is printed. Once received, a system Job Movement Transaction (FS72) is performed and the paperwork is reunited to the Bulk/UPS unpack operator (Diagram B - node 1-4).

2. System data for an order is incorrect, the problem is
addressed by production control personnel and fixed, upon which time the order is received, a FS72 is performed and the paperwork is returned to the Bulk/UPS unpack operator (Diagram B - node 3-7/4).

3. An Engineering Change is required for the order. In this instance the materials are placed on system interrupt and are maintained outside the simulation network (Diagram B - node).

Diagram A describes the Routing from Bulk/UPS Holding Area. Here, UPS/Bulk holding operators obtain processed paperwork from the Document Control Department. The paperwork and materials are reunited and routed to one of three areas in the network.

One possibility is that deliveries are moved to the Internal Trucking (IT) Drop Area (Diagram A - node 12). Material in this area is on-loaded by IT operators and moved to either the Stockroom Department or manufacturing and non-manufacturing areas outside the simulation network (Diagram A - node 13/14). The second possibility is that deliveries are moved to the Receiving and Inspection Department (RI) Drop Area (Diagram A - node 11).

The remaining portion of items (UPS) are classified as "internal request" material. In this instance the necessary individual is contacted and the material is stored in the holding area until pick-up (Diagram A - node 10).

Diagram C depicts detailed material Routing from R/I Drop Area. Here, materials arriving to the Receiving/Inspection Drop Area undergo an information system check for interrupt code and are prioritized for
inspection. Items that are found to be acceptable are forwarded to the
Stockroom Hold Area to await Stockroom Department processing (Diagram
C - node 5).

Items that do not immediately pass inspection are rejected to the
Reclamation Area for dispositioning (Diagram C - node 6). Reclamation
operators scrap, return material to vendors, or rework/repair the
deliveries. These items are processed outside the network.

3.5.1 Stockroom Processing

Three material categories are processed by the Stockroom
Department:

1. External UPS materials arriving from the Receiving and
   Inspection Department.
2. External BULK materials arriving from the Receiving and
   Inspection Department and Internal Trucking Department.
3. Internal materials arriving from auxiliary manufacturing and
   non-manufacturing departments.

The stockroom model is constructed from the available data regarding
these defined material categories.

BULK materials are transported from the Stockroom Department
Holding Area to designated pallet rack storage locations (Diagram
D - node 3/4). Processing times used in the model represent the time
required to identify the pallet, move and store the materials using
counterbalanced fork trucks.

Materials that require small parts storage are distributed among
three stockroom workstations where operators perform the necessary
stocking procedures and subsequently store the materials (Diagram D - 3/5/7). Presently, manual "man to part" stocking mechanisms are employed for these operations. Processing times used in the model for the operations include the time required for inspection of materials, walking to the storage area to stock items, and return to the workstation.

Exception items that are identified in the workstation inspection operations are routed to a stockroom clerk at which time the following problems are addressed (Diagram D - node 5/6 and Diagram E):

1. Bill of Material Errors (BOM) - BOM errors must be corrected by production control operators (Diagram E - node 5.1A/6B). Upon correction these materials are returned to the original workstation for processing (Diagram E - node 6/5).

2. Visual Damage - Visual inspection of items may result in detection of damaged parts. Parts suspected of damage must be examined by R/I personnel upon which time the items are approved for stockroom processing or maintained outside the simulation network (Diagram E - node 5.1B/6A).

3. Parts and Papers Do Not Correspond - This particular error also requires production control operator action (Diagram E - node 5.1C/6B). Subsequent to production control investigation these items either await initial workstation processing or are maintained outside the simulation network.

4. Shelf-Life - Required documents must be completed for items of this nature. Upon completion of the necessary operations
the items await stockroom processing at the original workstation (Diagram E - node 5.1D/6).

5. Inspection Identification - All materials that are processed in the stockroom require inspection ID stamps designating material routing. Items lacking the necessary identification require Production Control Department action, once obtained these materials are rerouted to the original workstation for stockroom processing (Diagram E - node 5.1E/6B).

6. Engineering Change - Engineering changes refer to the changes on hardware, i.e., rework or repair operations. Designated personnel within the MDC are responsible for correcting the problems. Materials requiring engineering changes are either permanently moved to operations outside the simulation network or corrected and returned to the original workstation (Diagram E - node 5.1F/6C).

In addition to the stocking of external inbound materials, the Stockroom Department must coordinate credit and issue operations. Materials that are returned to the stockroom are processed on a first-come first-serve basis at the same workstations discussed above. Three categories of credits are defined:

1. 451's - individual item returns from Manufacturing Departments.

2. 452's - packaged item returns from Manufacturing Departments.

3. Receipt of Materials (ROM's) - returned items that contain no identification resulting in exception credit processing
Issues or material requests are classified by five categories:

1. **End-Item-Requisitions (EIR's)** - system generated documents specify these government contract requirements.

2. **Unplanned Requisitions** — originate from manufacturing departments (failure or replacements) or vendors.

3. **Part-Number-Changes** — handwritten Production Control Department request to move materials to various storage zones.

4. **Stock to Stock** — external part number changes, that is materials to be moved from facility to facility.

5. **Kits** — requirements are obtained from Assembly Release Lists and filled on a due date basis.

Issues are processed at three stockroom inspection stations. Typical processing involves walking to storage areas to obtain parts, manual update of lot dispersal cards, scale count of items if required, placing items in shipping containers and movement to drop areas for pick-up (Diagram D - node 8-12). Errors or defects that are detected at inspection stations are returned to the original workstation for corrections (Diagram D).

The next section devotes considerable attention to the design of the stockroom simulation model. Note that it's logic follows directly from the description given in Section 3.5.1.

3.5.1.1 **Overview of Stockroom Model Design.**

This subsection is provided to illustrate the unique analysis capabilities of the MDC stockroom model. The main feature involves the
use of two distinct simulation orientations. In both cases "RESOURCE" operators are utilized as opposed to "ACTIVITY" operators. The term "resource" pertains to service units that perform various operations in different network locations. The term "activity" pertains to stationary service units. The concept of the "RESOURCE" operator is extended further to consider priority servicing of incoming entities.

In addition to these properties, the simulation model can be operated as a stand alone analysis tool. This is achieved by activating UPS and BULK "CREATE" nodes that are otherwise inoperable when combined with the Receiving Model.

Moreover, note that the model design is significant because the two simulation orientations are built directly into the logic and eliminate major recoding requirements for similar analysis. An effort to anticipate the needs of the user and the delivery of the most efficient, flexible, and user-friendly analysis tool stimulated its development. Specific instructions regarding the use of the simulation model is found in Section 3.5.1.2.

3.5.1.2 Description of Stockroom Model Logic.

This section describes the logic and analysis capabilities of the MDC Stockroom simulation model. The model is designed to capture the operating characteristics used to process the following transactions:

1. Internal Credits
2. External Receipts
3. Issues.

Three workstations process receiving transactions 1 and 2 and
three inspection stations process material request transactions (transaction 3). The stockroom clerk handles exception receipt processing.

Formulation of a database of operating characteristics for model input is accomplished by ongoing direct observation of work methods, analysis of existing system documentation and interviewing of personnel responsible for material processing. For this particular application, information specifying material, arrival types and volumes, workstation processing sequences, processing times, and material flow patterns were obtained. Figure 3.7 illustrates the logic structure of the model.

Note that Type A and Type B simulation is provided as part of the existing code. Also, the supervisor identified in both service stations is utilized to specify priority transaction processing. A discussion of other assumptions associated with the respective simulation orientations is given below.

3.5.1.3 Determination of Simulation Orientation.

When using the stockroom model the simulation orientation must be specified. The criteria for this specification is as follows: Type A simulation isolates the processing method of each individual service unit. An example of its use might be to prioritize Backorder processing at inspection stations 1 and 2 while prioritizing KIT transactions in inspection station 3. Hence, in addition to labor utilization analysis, a form of work scheduling is provided to the analyst.

Type B simulation assumes identical processing methods for the
Figure 3.7. Stockroom Model Logic Structure.
service unit. Hence, transactions are processed on a first-come first-serve basis. This orientation is most appropriate for macro-level service-unit requirement analysis. An example of its use might be to determine, in general terms, what staffing level is required to handle a 30% increase in receiving transactions.

Note that the simulation language does not allow for the same method of specifying service unit levels in "Resource" and "PREEMPT" nodes. And considering the above examples as legitimate requirements of the MDC model both modeling orientations are adopted. Continuing along this subject matter Section 3.5.1.4 provides instructions for manipulating the model code.

3.5.1.4 Code Manipulation for Type A Simulation.

As stated, Type A simulation employs "PREEMPT OPERATORS" to manipulate the sequence of transaction processing in the stockroom model. Four SLAM statements are required for this orientation:

1. Resource Block + RESOURCE/SUPV1,3
2. Preempt Node + PREEMPT(3)/HIGH(1),SUPV1
3. Act Node + ACT/16,.0167
4. Free Node + FREE,supv1/1,1;

When using PREEMPT operators only one resource (or labor unit) is allowed. Therefore, to consider more than one supervisor and/or three (one-labor-unit) work/inspection stations, requires the addition of the four statements shown above. Note that prioritization of transaction processing is accomplished with the HIGH/LOW specification in the SLAM statement (number 2 above). To facilitate use of this capability
transaction attribute numbers are easily changed by adding constant values to their present levels. When using Type A simulation it will be necessary to specify routing labels in the stockroom model statement numbers 122, 125, 232, 270, 274, and 331 (Simulation Code - see User's Manual. These statements must be of the format:

1. For Workstations + ACT/#, duration, condition, SlA
2. For Inspection Stations + ACT/#, duration, condition, S2A;

where SlA/S2A are the node labels specifying the specific location of Type A processing in the simulation model.

The final adjustment required for Type A orientation is the "dummy deletion" of Type B processing in the model. This simple procedure is accomplished by inserting a semicolon in column 1 of statements number 14, 20, 160-165, and 308-313.

3.5.1.5 Code Manipulation for Type B Simulation.

Type B simulation employs "RESOURCE OPERATORS" to measure labor unit requirements for given workloads in the stockroom workstation (receiving) area and the inspection station (issue) area. Four SLAM statements are required for this orientation:

1. Resource Block → RESOURCE/SPV1B(X),15
2. Await Node → AWAIT(15),SPV1B/1
3. Act Node → ACT/27,ARTIB(9)
4. Free Node → FREE,SPV1B/1;

This orientation is very efficient for manpower planning because the number of labor units per work/inspection station is manipulated using one SLAM statement. Varying the level of (X) in the Resource Block
will accomplish this objective (SLAM statement 1 above).

When using Type B simulation it will be necessary to specify routing labels in the stockroom model statement numbers 122, 125, 232, 270, 274 and 331. These statements must be of the format:

1. For Workstations \(+\) ACT/\#, duration, condition, S1B;
2. For Inspection Stations \(+\) ACT/\#, duration, condition, S2B;

where S1B/S2B are the node labels specifying the specific location of Type B processing in the program.

The final adjustment required for the Type B orientation is the "dummy deletion" of Type A processing in the model. This simple procedure is accomplished by inserting a semicolon in column 1 of statements number 13, 19, 132-137, and 280-285.

The above analysis capabilities of the MDC Stockroom model and the subsequently recoded Receiving Operations model are particularly important when considering material handling equipment. For example, the impact of devices categorized as Automatic Storage and Retrieval Systems (ASRS), that automatically route materials to designated workstations can be thoroughly investigated with Type A analysis. Finally, and most important, the simulation models can be used to determine the effectiveness of a particular distribution method by computing variations in system performance measures. The next section discusses a general approach to identifying system performance measures as well as the specific indicators of importance in the case study.
3.6 **Overview of Performance Measure Determination.**

One of the primary operating objectives of material management and distribution facilities is to make the most efficient use of resources while satisfying demand from other departments in the production cycle. A typical set of operations used to meet the objectives include:

1. Receiving.
2. Identification and sortation.
3. Movement of materials to storage.
4. Storage.
5. Retrieval from storage.
6. Packing.
7. Movement of materials to auxilary departments.
8. Record keeping.

If one also incorporates throughput time minimization as an objective the selection of performance measures that indicate the functional efficiency of the system can be extracted.

Logically, the front end of the operations involved with material management policy analysis is the requirement to efficiently process incoming materials. Therefore, performance measures in this operation must reveal information regarding the accuracy, speed and maintenance or over all control of the system of the initial processing. These same three parameters (speed, accuracy, and maintenance) can be applied to each operation described above so that information pertaining to the cycle time and control of materials is available. Further, (as Figure 3.8 illustrates) once the individual cycle times are determined the
ability to ascertain throughput time for material requests is at hand. Accurate information regarding throughput time can, of course, reduce costs associated with procurement and production scheduling.

3.6.1 MDC Performance Measures.

Incorporating user-defined performance measures into the simulation model is a fundamental design step. Regarding the specifics of the case study, the same systematic approach (as in Section 3.6) to determining system performance measures was adopted. The following performance measures were determined to be most important for the effective management of the MDC:

1. Dock processing time for Chemical orders.
2. Dock processing time for Bulk orders.
3. Dock processing time for UPS orders.
4. Internal Trucking Material Movement time.
5. Total Receiving Operations Time.
6. Bulk-order time in system (receiving to final storage).
7. UPS-order time in system.
8. Stockroom processing time for Credit transactions.
9. Stockroom processing time for Unplanned transactions.
10. Stockroom processing time for Back-order transactions.

Specific values computed for these performance measures are part of the descriptive output analysis of SLAM. Each policy alternative possesses a database containing this information which is subsequently used in decision analysis.

It is important to note that the construction of this database is
Figure 3.8. Framework for Determining Performance Measures in a Materials Distribution Environment.
extended to what will be referred to as an "Applications Matrix" (A-matrix). This matrix proved very helpful in simulation design and established a tangible link between the simulation model and the Decision Model (to be discussed in Section 3.7). The matrix is used to identify relationships between material handling equipment capabilities and MDC processing operations. The subsection that follows details the development of the "Applications Matrix".

3.7 Use of the Applications Matrix.

Application matrices relate decision alternative attributes to material management system operations. The matrices are two dimensional with one dimension designating simulation distribution system parameters and the other dimension designating the operating specifications of the handling alternative being investigated. A zero-one (0-1) convention is used to develop the matrix. After the axes of the matrix are labeled, a determination is made as to whether or not the alternative's attributes have an impact on the logic (code) of the model. If so a one (1) specification is used to denote that changes are required whereas if no changes are required in model logic a zero (0) is specified.

The primary usefulness of the matrix is that of a checklist, ensuring that the impact of alternative methods be fully incorporated into the simulation analysis. The concept is extended for use in the decision model by replacing the dimension of simulation model parameters with non-model parameters such as cost, safety, etc.

The attention devoted to the matrix in this research is an
extension of efforts to show a systematic procedure for categorizing and investigating alternative material distribution methods. An example A-matrix set (see Figures 3.9(a) and 3.9(b)) is presented below that might be used for consideration of a conveyor in receiving operations. The fully developed matrices will be presented in Chapter 4 along with respective material handling devices.

Figure 3.9(a) is interpreted as follows: The implementation of a conveyor system in the receiving operations will require changes in the SLAM Code. Specific changes will be made to the present duration times for UPS and Bulk material movement. Figure 3.9(b) is interpreted as follows: Cost, Safety, System Control and Asthetics can be considered in the decision model and weighted according to importance.

The conveyor alternative would in turn undergo full investigation with the specification of the A-matrix set incorporated into the model code. Experimental studies are then evaluated in terms of variations in the simulated performance measures.

If we refer to key measures in the simulation model as tangible parameters, then there also exists some set of non-model parameters such as costs, safety, etc. that must be considered in the evaluation process. The difficulty of course is trading-off the benefits of the model and non-model parameter features in the decision making process.

The next section will describe a mathematical tool that can in fact, enhance the decision makers ability to assess the trade offs associated with alternative material handling equipment configurations in a materials distribution environment. The section demonstrates the
### MDC System Performance Measures

**Figure 3.9(a). Example Simulation A-Matrix for Conveyor in Receiving Operations.**

<table>
<thead>
<tr>
<th>Equipment Parameters</th>
<th>Speed</th>
<th>Space Req'd</th>
<th>Wt. Capacity</th>
<th>Cost</th>
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</table>

<table>
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<tr>
<th>Movement Identifiers</th>
<th>Material Move</th>
<th>Move Route</th>
<th>Route B.O.</th>
<th>Credit on Hold</th>
<th>Hold from Dock Area</th>
<th>Area Stockroom</th>
<th>Stockroom</th>
</tr>
</thead>
</table>

### MDC System Performance Measures

**Figure 3.9(b). Example Non-Model Parameter A-Matrix for Conveyor in Receiving Operations.**

<table>
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<th>Equipment Parameters</th>
<th>Speed</th>
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<th>Cost</th>
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<table>
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<th>Performance Measures</th>
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<th>System Flexibility</th>
<th>Asthetics</th>
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</table>
use of Decision Theory value functions as reviewed in Chapter 2 and
presents a step by step method to integrate assessment concepts,
additive equations, and the above simulation model for the purpose of
developing a Material Management Decision Support Model.

3.8 Creating the Decision Support Model.

The purpose of integrating Decision Theory with simulation
analysis is to enhance the decision maker's ability to evaluate
multiattribute alternatives in a systematic manner. Note that
"integrate" in this context does not refer to a physical linkage of
code but rather the ability to incorporate simulation output with other
criteria for evaluation and selection specification from a set of
alternatives. The significance of the interface is two fold:

1. Simulation output and other policy factors can be
   simultaneously considered as selection criteria.

2. A computerized decision model makes the decision analysis
   procedure efficient, effective, and in effect, "user-
   friendly".

The decision model is composed of three primary phases of computations.
The first phase uses a slight variation of the Churchman-Ackoff
assessment technique to rank and weight the parameters to be
considered. The Churchman-Ackoff model is adopted because it is
representative of a direct assessment technique found to be highly
applicable to multiattribute decision analysis. This is due to its
ease of application and relative robustness to interdependencies
between attributes. This variation of the procedure involves setting
the most important parameter equal to 1.0 as opposed to an unconditional specification. This modification is believed to make the model more intuitive for the untrained user and does not significantly alter the technique. Prior to phase 2 processing, a consistency check of input is conducted. Provided all ranking and weightings are consistent phase two of the model is executed. The second phase uses an additive model to score the alternatives. Phase three of the model determines the final selection alternative based on the decision maker's weighted preferences. The entire algorithm will be referred to as the Material Management Decision Support Algorithm and is the final component of the Material Management Decision Support System developed in this research. Figure 3.10 depicts the framework for the Decision Support System. The formal algorithm is presented in the next subsection along with an example application.

3.8.1 Material Management Decision Support Algorithm.

The step by step procedure for determining final policy selection from a set of alternatives is presented below. The algorithm is an extension of the use of traditional simulation analysis and Decision Theory that provides a tool for policy analysis.

Step 1: Identify the simulation model parameter(s) and/or performance measure(s) that require management attention. \((P_1, \ldots, P_m)\)

Step 2: Identify the non-model parameters or performance measures that are used for project justification/evaluation proposals. \((P_{m+1}, \ldots, P_n)\)
Figure 3.10. Framework of Material Management Decision Support System.
Step 3: Select the corresponding material handling mechanism(s) to be analyzed in the model.
(Alternative j, j = 1,...,n).

Step 4: Develop an "Applications matrix" (A-matrix) relating equipment alternative j to model parameters (p_1,...,p_m).

Step 5: Develop an "Applications matrix" relating equipment alternative j to non model parameters (p_{m+1},...,p_n).

Note: Steps 1 thru 5 establish reference points to adjust the model base conditions.

Step 6: Simulate the distribution operations under alternative j.

Step 7: Obtain values for P_1,..., P_m.

Step 8: Use assessment technique to prioritize P_1,...,P_n and assign relative weights, w_1,...,w_n that are consistent with parameter prioritization.

Note: Step 8 is an iterative procedure that establishes consistency in decision makers preference among P_1,...,P_n and between w_1,...,w_n.

Step 9: Normalize the relative weights
i.e., \( \sum_{j=1}^{n} w_j \) is normalized so that \( \sum_{j=1}^{n} w'_j = 1 \).

Step 10: Score the alternatives j using the additive model and simulation results x_j for each respective parameter p_j.

\[
\text{SCORE} = \sum_{i=1}^{n} w'_i x_j
\]
where \( x_j = \frac{p_j}{\max_{j} p_j} \)

Note that when the preference effect of a performance measure is "negatively scaled" i.e., preferability decreases with increases in the
level of that measure, the corresponding $w_i$ coefficient is assumed to
be negative.

Step 11: Select the appropriate alternative based on "scaling
orientation".

The 11 step algorithm represents the integration of two
mathematical models. The primary idea is to use the descriptive
nature of simulation analysis within the normative context of decision
theory. The algorithm represents the product of the research effort
which focuses on material management policy selection. A hypothetical
example of the application of the algorithm is presented below.

3.8.1.1 Example Problem.

Step 1: Identify the key simulation model parameter(s) or performance
measure(s) that should be considered in the distribution
system configuration selection process.

- Model Parameters: Material ID Move UPS to Hold Area
  Sort Materials Route B.O. from Stockroom
  Move Bulk to Hold Area

Step 2: Repeat Step 1 for non-model parameters.

- Non Model Parameters: Cost Amount of Manual Handling
  Shop Floor Control Flexibility

Step 3: Select the corresponding alternative material handling
mechanism(s) to be analyzed in the simulation model.

- Equipment: Conveyors
  Lift Truck

Step 4: Develop an "applications matrix" (A-matrix) relating the
equipment specifications to model parameters ($P_1, \ldots, P_m$).

These relationships will be used as guides to adjust the model base
conditions. (See Figures 3.11(a) and 3.11(b) for example A-matrix set.)

Note: A zero-one convention is employed for the matrix. 1 - indicates that changes are required in the model. 0 - indicates that no model changes are required.

Step 5: Develop an "Applications matrix" (A-matrix) relating the equipment specifications to the non-model parameters \( (P_{m+1},...,P_n) \). These relationships will be used when developing the value functions.

Step 6: Run the model for the configurations specific performance level computations.

Note: At this point the assessment technique is used to prioritize \( P_1,...,P_n \).

Step 7: Ask the decision maker to specify the number and identification of the parameters to be analyzed with the Decision Support System.

- \( P_1 \) = UPS Dock to Stock Time
- \( P_2 \) = Bulk Dock to Stock Time
- \( P_3 \) = Backorder Time In
- \( P_4 \) = Cost

Step 8: Use the assessment technique to prioritize \( P_1,...,P_n \). Assign relative weights \( w_1,...,w_n \) that are consistent with parameter prioritization. (Perform consistency check).

A) Decision Maker's Preferences

This process refers to the parameter that weighs most heavily in the decision making process. Other preferences are considered in descending
## Conveyor

<table>
<thead>
<tr>
<th>Equipment Parameters</th>
<th>Speed</th>
<th>Space Req'd</th>
<th>Wt. Capacity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mat'l Move</th>
<th>Move</th>
<th>Route</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPS to</td>
<td>Bulk</td>
<td>B.O.</td>
<td>Credits</td>
</tr>
<tr>
<td>on Hold</td>
<td>to Hold</td>
<td>From</td>
<td>from</td>
</tr>
<tr>
<td>Dock Area</td>
<td>Area</td>
<td>Stockroom</td>
<td>Stockroom</td>
</tr>
</tbody>
</table>

**Distribution System Operations**

Figure 3.11(a). Example Simulation A-Matrix for Conveyor.

## Non-model Parameters

<table>
<thead>
<tr>
<th>Equipment Parameters</th>
<th>Cost</th>
<th>Safety</th>
<th>System Control</th>
<th>Flexibility</th>
<th>Asthetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Space Req'd</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Wt. Capacity</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cost</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 3.11(b). Example Non-Model Parameter A-Matrix for Conveyor.
order.

1\textsuperscript{st} - UPS Dock to Stock Time \( \rightarrow P_1 \)

2\textsuperscript{nd} - Cost \( \rightarrow P_2 \)

3\textsuperscript{rd} - Bulk Dock to Stock Time \( \rightarrow P_3 \)

4\textsuperscript{th} - Backorder Time in System \( \rightarrow P_4 \)

therefore \( p_1 > p_2 > p_3 > p_4 \).

Step 8 continued.

B) - Assign relative weights that are consistent with parameter prioritization.

\[ P_1 > P_2 \quad \text{and} \quad P_3 \quad \text{and} \quad P_4 \quad \Rightarrow \quad w_1 > w_2 + w_3 + w_4 \]

Set \( w_1 = 1 \) then \( w_2 + w_3 + w_4 \) might equal .8

\[ 1 > .8 \quad \text{consistency check - OK} \]

- Now assign the individual weights to \( w_2 \) - \( w_n \) based on parameter prioritization.

recall \( w_1 = 1 \) \( \Rightarrow \) \( .8 = w_2 + w_3 + w_4 \)

- Decision Maker Weight Assignments

\( w_2 = .5, \quad w_3 = .2, \quad w_4 = .1 \)

\( P_2 > P_3 \quad \text{and} \quad P_4 \quad \Rightarrow \quad w_2 > w_3 + w_4 \)

\[ .5 > .2 + .1 \quad \text{consistency check - OK} \]

Final preferences of decision maker

\( w_1 = 1, \quad w_2 = .5, \quad w_3 = .2, \quad w_1 = .1 \)

- Assessment Procedure complete -

Step 9: Normalize the relative weights.

\[ \sum_{j=1}^{n} w_j \quad \text{so that} \quad \sum_{j=1}^{n} w'_j = 1 \]
Calculations:

A. \[ \sum_{j=1}^{n} w_j = 1 + .5 + .2 + .1 \]
   \[ = 1.8 \]

B. Normalized

\[ \begin{align*}
    w_1 &= \frac{1}{1.8}, & w_2 &= \frac{.5}{1.8}, & w_3 &= \frac{.2}{1.8}, & w_4 &= \frac{.1}{1.8} \\
    w'_1 &= .56, & w'_2 &= .28, & w'_3 &= .11, & w'_4 &= .05 \\
    \sum_{j=1}^{n} w'_j &= .56 + .28 + .11 + .05 = 1.0
\end{align*} \]

Step 10: Score the alternatives using the additive model and simulation results for each respective parameter.

- From Simulation Output: Assume similar procedure conducted for Lift Truck.

<table>
<thead>
<tr>
<th>Conveyor</th>
<th>Truck</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P'_1 ) = 8 days</td>
<td>( P'_1 ) = 6 days</td>
<td>( P'_1 ) = 10 days</td>
</tr>
<tr>
<td>( P'_2 ) = $50,000</td>
<td>( P'_2 ) = $70,000</td>
<td>( P'_2 ) = 0</td>
</tr>
<tr>
<td>( P'_3 ) = 11 days</td>
<td>( P'_3 ) = 9 days</td>
<td>( P'_3 ) = 12 days</td>
</tr>
<tr>
<td>( P'_4 ) = 13 days</td>
<td>( P'_4 ) = 13 days</td>
<td>( P'_4 ) = 13 days</td>
</tr>
</tbody>
</table>

\[ f(x_1, \ldots, x_n) = \sum_{i=1}^{n} w'_i x_i \]

\[ x_i = \frac{F[P'_j]}{\max_{j=n} P'_j} \]

Scoring Model*:

Base Score: \[ .56(10/10) - .28(0/70K) - .11(12/12) - .06(13/13) \]

\[ = -0.73 \]

Conveyor Score: \[ -.56(8/10) - .28(50k/70k) - .11(11/12) - .06(13/13) \]

\[ = -0.81 \]
Truck Score: \(-.56(6/10) - .28(70k/70k) - .11(9/12) - .06(13/13)\)
\[= -.76\]

Step 11: Select the alternative with the least negative score. Select Base for operations.

*Note that when the preference effect of a performance measure is "negatively scaled", i.e., preferability decreases with increases in the level of that measure, the corresponding \(w_i\) coefficient is assumed to be negative.

3.9 Summary and Conclusions.

This chapter presented the methodological framework of a Material Management Decision Support System. The system is composed of two computer models. The first model uses the "service system" concept of simulation analysis to characterize the operations of a materials distribution facility. User-defined performance measures computed in the model establish a common criteria for measuring alternative work methods in the actual system. The second model is based on multiattribute decision theory. Its purpose is to aggregate output from the simulation model with non-model parameters for final policy selection from a set of alternatives. Chapter 4 outlines in detail how the system is to be implemented in the industrial environment providing the case study.
CHAPTER 4

DECISION SUPPORT SYSTEM IMPLEMENTATION

This chapter details application of the Material Management Decision Support Algorithm to the case study distribution center environment. The first half of the chapter focuses on simulating the existing operations in the UDC. After the base line performance is established, alternative material handling equipment scenarios are introduced into three primary operations of the distribution system. The important concepts demonstrated from these simulations include:

1. Use of the model as an investigative tool.
2. Design of material handling equipment using the SLAM code.

The second half of the chapter focuses on the design features of the Computerized Decision Model. Special attention is given to the identification and measurement of parameters for decision analysis as well as interpretation of model output.

The two topics are linked by identifying model and non-model attributes of the simulated handling devices. Model attributes refer to the values computed for the various distribution system performance measures in the simulation analysis. Non-model attributes are features of the policy alternatives that are not characterized in the simulation (i.e., safety, installation cost, etc.). The decision model is designed to incorporate both parameter types as criteria for policy evaluation and final selection.
4.1 Objectives of the Simulation.

The major objectives of the simulated operations are three fold:

1. To demonstrate the use of the MDC simulation model for material management policy analysis.

2. To simulate the present operating methods in the MDC so that a base system performance level can be determined. This base will act as a standard when evaluating material handling alternatives.

3. To examine the relationship between the perceived control of operations and the actual calculated efficiency associated with implementing the selected material handling devices.

Requirements of the first two objectives include modifying SLAM code to reflect changes in processing times at the various workcenters in the distribution network. Highlighting conditions under which the utilization of alternative code orientations (A or B) are more appropriate is also discussed. With the model parameters and structure fully specified, the model is run for some simulated time period. Upon completion, output analysis is computed for user defined performance measures and built-in statistics. This information is used to identify processing bottlenecks, workstation utilization, etc.

The third objective is accomplished by introducing operating characteristics of material handling equipment into the simulation network. Statistical output for the handling equipment is stored in device specific databases. Selected parameter values from the database are used as input for the Decision Model to evaluate the policy
alternatives along common criteria.

4.2 Simulation Overview.

Type A and Type B simulation will be demonstrated throughout the investigation of MDC operating methods. In all simulations system throughput time is considered to be composed of three primary components:

2. Stockroom Receiving cycle Time.

The base system throughput time is calculated from the existing operating methods in the MDC. Operating methods are defined in terms of service units per workstation and material transport mechanism. Type B simulation is used in this case to determine the present levels of performance.

The order in which the material handling policy alternatives are introduced represents a prioritization of potential enhancements to the MDC environment. Three material handling systems are simulated:

1. Barcode scanners.
2. Power Driven Carts.

The first handling system to be simulated depicts Bar code scanning and labeling devices. Priority is given here because the fast and reliable identification of materials is extremely critical if subsequent routing, monitoring, and control of materials is to be successful.
The second handling system to be simulated depicts powered cart capabilities. Stimulus for the investigation evolves from the fact that a considerable amount of distribution system operating expenses are directly related to material transport. The cart concept offers potential for increased productivity by moving more material per transport cycle time.

Having focused on the receiving and movement of materials in the distribution system, the final material handling system is specific to stockroom operations. The efficient processing of transactions in the stockroom defines the upper boundary of this research regarding simulation analysis. Towards this end, the operating characteristics of carousel systems and automatic storage and retrieval systems are simulated. A demonstration of Type-A code orientation is included within this handling framework characterizing the prioritization of stockroom order processing. The tangible benefits derived from simulating the material handling equipment is presented in terms of system performance levels that make up the distribution system throughput time.

Section 4.3 further outlines analysis of the MDC operations. From this investigation the present level of resources used for material distribution are compared with strategically placed alternative material handling equipment in the processing operations. A review of the attributes associated with the equipment as discussed in Chapter 2 is also presented. This information is used to construct a device specific data base (A-matrix) which contains parameter values that act
as input to the simulation model and the decision model.

4.3 Simulation of the Existing MDC Operations.

This section discusses simulation of the MDC operations described in Chapter 2. As stated, the present method of material management includes the following operations:

1. Receiving Dock Unloading and Sorting.
2. Staging of material awaiting materials information system update.
3. Material transport to inspection.
4. Inspection of incoming materials.
5. Movement to Storage.
7. Order Picking.

Note that fork trucks are used to transport materials between manually operated workstations. Recall also that initially two separate models constitute the distribution network. Prior to linkage, operations 1-4 reflect workstation resource levels designated as base conditions by the case study firm. Therefore, this section will focus on the linkage of the models and establishing a base condition for operations 5-7.

This process is especially significant when using the stockroom model (operations 5-7) because a specific code structure is built into the network that facilitates the general determination of resource requirements (service units) per workstation. This code structure is referred to as "Type-B" orientation and is discussed in Section 3.5.1.2.
Figure 4.1 illustrates the linkage of the Receiving Operations and Stockroom model to obtain the total MDC network. The structure is modified accordingly to reflect the implementation of material handling equipment. The equipment that is simulated is discussed in the next few sections. Within each section pertinent information regarding the simulation purpose, assumptions, design, and data requirements is presented.

4.4 Overview of Simulation for Material Handling Equipment.

Simulating automated material processing in the Receiving, Material Transport, and Stocking operations allows for the practical investigation of MDC operations. Parameter adjustments for the simulations are based upon equipment operating characteristics (i.e., items handled per unit time). Calculations describing the performance of the handling systems are provided within each subsection. Where precise calculation could not be obtained, the expertise of the MDC personnel is adopted. An "A-matrix" is produced for each alternative to act as a formal check for modifications to model code. The end result of these investigations will be three policy alternatives regarding material management in the MDC.

4.5 Simulation of Barcode Equipment for Receiving Operations.

The first simulation examines how barcode scanning devices and inhouse labeling might be incorporated into the MDC receiving operations. The receiving function is used as a starting point because the area is:

1. A logical starting point for accomplishing material management
Figure 4.1. Flowchart for MDC Simulation Model.
system integrity.
2. Labor intensive.
3. The physical link with vendors, and if monitored properly can ensure efficient procurement strategies.
4. A major contributor to total MDC system throughput time.
5. Susceptable to more efficient and effective work methods.

Recall that incoming containers unloaded at the Receiving Dock are opened by operators to obtain packing slips required to update the materials information system. This process creates a delay in material transport and increases the chance for mismatching and/or damaging goods. An alternative method for identifying materials is to use barcode scanning equipment.

Hand held, moving-beam barcode scanners read analog barcodes attached to the containers, decode the information and transmit a digital signal to the host material inventory system computer. Note that an assumption is made concerning pre-labeled containers arriving to the Receiving Dock. This is accomplished by vendor generated labels or by mailing labels (generated in house) along with the initial purchase order to vendors.

4.5.1 Considerations for Restructuring the SLAM Code.

Barcode scanning capabilities are incorporated into the receiving function by assuming the following set of operations:

1. UPS containers and bulk items are recorded to the inventory system by Dock operators.
2. The entire process of recording includes scanning the
container and moving to the next container on the pallet.

3. Assume the duration to scan, orient and affix inhouse labels is 5 minutes.
   
   (A) Assign the barscan process duration to an attribute number: \( \text{ATRIB(10)} = 0.0833 \)
   
   (B) Perform the operation in the Bulk/UPS Hold Area
   
   SLAM CODE: BULK ACT/19, ATRIB(10);
   
   UPS ACT/31, ATRIB(10);

4. Eliminate the present operation of opening the container and separating the materials and documents in the SLAM code for UPS materials. This also includes eliminating the delay for document control processing. Diagram 3.2A node 5-7.

5. Route "pass" items to internal trucking and Receiving/Inspection staging areas.

6. Route exception materials to a hold area for corrections.
   
   These materials wait for inventory control system operators.

   Figure 4.2 reflects the restructured SLAM code simulating barcode scanning capabilities for incoming materials. The analysis of the simulation is presented in Chapter 5.

   This figure is based on the preliminary identification of code changes designated in the simulation model "A-matrix". The A-matrix for the barscan system is presented in Figure 4.3.

   Note that the A-matrix shown in Figure 4.3 represents a macro-level application of the concept. Although a formal step in the algorithm, the degree to which the A-matrix is developed is totally
Figure 4.2. SLAM Code Structure Reflecting BARCODE Operations.
Barcode System - Simulation "A-Matrix"

<table>
<thead>
<tr>
<th>Equipment Parameters</th>
<th>Receiving Operations</th>
<th>Material Transport</th>
<th>Stocking Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wand</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Portable</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Weight</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Memory</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Price</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 4.3. Simulation A-Matrix: Barcode System.
user dependent. The BARCODE A matrix in Figure 4.3 indicates that using hand held portable scanners will require changes in the Receiving operations. The material transport function is now also affected in terms of routing pass and exception materials.

Continuing with the sequence of operations in the distribution system, the next area for potential enhancement involves the movement of materials. Accordingly, Section 4.6 describes the simulation framework for implementing power driven carts to transport UPS items from the UPS Hold Area to the Receiving and Inspection Department.

4.6 Simulation of Power Driven Carts for UPS Transport.

The second simulation examines how power driven carts might be incorporated into the MDC material transport operations for UPS deliveries. The material transport function is examined to:

1. Investigate an alternative to single pallet load movement of materials.
2. Provide information on how such a system could affect material throughput time.
3. Provide information on how other system performance measures, such as operator utilization are affected by the devices.

Recall that currently in the MDC UPS material transport is accomplished by counter balanced fork trucks. These trucks are fairly flexible but are restricted to the amount of materials that can be moved at any one time to one pallet load. The potential for productivity increase is contingent upon a method that will deliver greater than or equal to the same amount of material but at reduced
An alternative method for moving materials between MDC operations is to use power driven carts. This equipment includes one power unit pulling loaded carts or trailers. Although the movement of materials in this alternative is not as continuous as an alternative conveyor system, advantages do exist in terms of portable work-in-progress storage, variation in the number of carts towed (device utilization), and flexible routing.

4.6.1 Considerations for Restructuring the SLAM Code.

The operating characteristics of the cart equipment will be simulated in the MDC network by creating batch arrivals in the cart loading and unloading areas. Duration is based on device speed and capacity. A more specific set of SLAM code changes are described below.

1. Note that presently, purchase order transactions are created for Receiving Dock operation processing. An assumption is made that a one to one correspondence exist between purchase orders and UPS materials.

2. Employ a "GATE" operator (SLAM code) to store the materials until a cart is available for transport.

3. Design a counting system into the code specifying the number of UPS arrivals so that the appropriate number of carts are utilized to move the materials.

4. Note that while the total transport time remains to be 5 minutes, duration must be calculated and assigned to the
individual items to achieve the cart handling effect.

5. Currently it requires 5 minutes to move one UPS purchase order to the Inspection Department. Assume that the adopted cart system is capable of transporting 10 items per trip. In this instance it still requires 5 minutes to move one pallet load so the total duration/P.O. is equal to 5 minutes. If 11-20 items await transport, 2 carts will be used and the time required to move the material must be computed. In this instance the duration is divided by two to reflect moving twice the amount of materials within the 5 minute period. The time used for the simulation run is therefore set to 5 minutes/2 carts = (2 1/2 minutes)/cart. This same logic applies to moving 3 carts or more. That is, the original duration is divided by the number of carts to reflect the gain accomplished with a multi-item transport system. The complete set of calculations used for SLAM code changes are given below.

<table>
<thead>
<tr>
<th>No. Cart(s)</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5 min. = .0833 hr.</td>
</tr>
<tr>
<td>2</td>
<td>5/2 = 2 1/2 min. = .0417 hr.</td>
</tr>
<tr>
<td>3</td>
<td>5/3 = 1 2/3 min. = .0278 hr.</td>
</tr>
<tr>
<td>4</td>
<td>5/4 = 1 1/4 min. = .0208 hr.</td>
</tr>
</tbody>
</table>

6. Note that a timing mechanism is built into the network to schedule work hours for cart operators at 9-9:30 am, 11-12:30 pm, 2-2:30 pm, 4-5:30 pm.
This schedule is random and in contrast to the assumption of full workday availability for the presently used fork trucks.

The A-matrix developed for simulating cart handling devices is presented in Figure 4.4. Interpretation of the A-Matrix indicates that due to the dimension of the cart system some adjustments may be required in receiving regarding time to load the cart, etc. Material transport time is directly affected by the number of carts used per service trip.

The next simulation involving material handling equipment is specific to the Stockroom Department. In an attempt to reduce the cycle time of issue transactions a policy alternative for carousel systems and automatic storage and retrieval systems is investigated.

4.7 Simulation of Carousel/Automatic Storage and Retrieval Systems.

The third simulation examines the potential effect of semi-automatic and automatic storage and retrieval systems in the stockroom. The stocking and order picking function is examined because the operation is:

1. Labor intensive.
2. Susceptible to equipment update.
3. Capable of increased productivity if a formal work schedule is adopted.

Recall that presently, operators (stocking and retrieval) must leave their immediate work area to process transactions in the stockroom. The operators are required to walk to storage bins and manually locate the specific stocking location of interest. Several
<table>
<thead>
<tr>
<th>Equipment Parameters</th>
<th>Receiving Operations</th>
<th>Material Transport</th>
<th>Stocking Operations</th>
<th>MDC Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension (carrier)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Weight Cap.</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Dimension (cart)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Costs</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4.4. Simulation A-Matrix: Cart System.**
114

potential problems are associated with this procedure:

1. Frequent trips away from the workstation are counter
   productive.
2. Valuable time is lost in walking to/from the storage bin.
3. Valuable time is lost searching for the correct storage bin.

An alternative to the present method is to adopt carousel
equipment or automatic storage and retrieval equipment for stocking
operations.

4.7.1 Considerations for Restructuring the SLAM Code.

The following set of assumptions are used to incorporate the
operating characteristics of the devices in the SLAM code.

1. Note that the present time used to represent transaction
   processing times is comprised of three components.
   (A) Time to walk to the storage area.
   (B) Time to search, locate, and stock/retrieve items.
   (C) Time to return to workstation.

2. With regard to total duration, the percent contribution of
   each component is as follows:
   (A) Time to walk to storage = 25%.
   (B) Time to search, locate, and store/retrieve = 50%.
   (C) Time to return to workstation = 25%.

3. Implementation of the equipment is expected to have the
greatest impact on issue transactions in the stockroom.

4. The duration for new issue transaction processing times are
calculated as follows:
(A) Implementation of carousels is expected to reduce the time to locate and store/retrieve materials by 50%.

Equation for processing time:

\[
\text{New Time (Carousel)} = \text{Base Time} - \frac{\text{Time to Stock/Retrieve Materials}}{2}
\]

(B) Implementation of ASRS is expected to reduce the time associated with material transport by 25%.

Equation for processing time:

\[
\text{New Time (ASRS)} = \text{Base Time} - \frac{\text{Time to Stock/Retrieve Materials}}{2} - \frac{\text{Time to Transport Material}}{4}
\]

Listed in Table 4.1 are the calculations associated with implementing the carousel system or the ASRS into the Stockroom. Note that all times are given in hours.

The A-matrix developed for simulating semi-automatic and automatic storage and retrieval devices is presented in Figure 4.5. The A-matrix indicates that consideration of the Storage and Retrieval System is specific to the Stockroom therefore, processing durations are affected. Within the Stockroom work methods, some guidelines should be adopted to consider the operating capabilities of new equipment. To demonstrate this step equations to calculate new processing durations for issue transactions are provided.

Simulation of storage and retrieval systems is the third and final policy alternative investigated in case study. Information concerning the purpose, objective, and method of implementation is provided for each scenario. The next step in preparing for policy evaluation is to
Table 4.1. Issue Transaction Calculations for Implementing Carousel and ASRS Equipment.

<table>
<thead>
<tr>
<th>TRANSACTION</th>
<th>BASE DURATION</th>
<th>STOCKING/RETRIEVAL $DUR$</th>
<th>$REDUCTION$</th>
<th>CAROUSEL DURATION</th>
<th>REDUCTION IN TRAVEL TIME ASSOCIATED WITH ASRS</th>
<th>ASRS DURATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>KITs</td>
<td>1</td>
<td>.3</td>
<td>.5</td>
<td>1=.5/2+.75</td>
<td>.125</td>
<td>.625</td>
</tr>
<tr>
<td>End Item Requisitions</td>
<td>.38</td>
<td>.18</td>
<td>.5</td>
<td>.35-10/2+.27</td>
<td>.045</td>
<td>.225</td>
</tr>
<tr>
<td>Unplanned Requisitions</td>
<td>.08</td>
<td>.04</td>
<td>.5</td>
<td>.08*0.04/2=.06</td>
<td>.01</td>
<td>.05</td>
</tr>
<tr>
<td>Part Number Changes</td>
<td>.075</td>
<td>.0375</td>
<td>.5</td>
<td>.075-.0375/2+.056</td>
<td>.0094</td>
<td>.0466</td>
</tr>
<tr>
<td>Stock to Stock</td>
<td>.325</td>
<td>.1625</td>
<td>.5</td>
<td>.325-.1625/2+.24375</td>
<td>.0406</td>
<td>.20315</td>
</tr>
<tr>
<td>Back Orders</td>
<td>.250</td>
<td>.125</td>
<td>.5</td>
<td>.250-.125/2+.1875</td>
<td>.03125</td>
<td>.13625</td>
</tr>
</tbody>
</table>

Note: All times in hours.
### Storage and Retrieval - Simulation A-Matrix

<table>
<thead>
<tr>
<th>Transport Speed (ASRS)</th>
<th>Command Type (Single-Dual)</th>
<th>Storage Orientation (Random, other)</th>
<th>Capacity</th>
<th>Receiving Operations</th>
<th>Material Transport</th>
<th>Stocking Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure 4.5.** Simulation A-Matrix ASRS.
determine pertinent non-model parameters for analysis in the decision model. Section 4.8 discusses the construction of A-matrices for non-model parameters.

4.8 A-MATRIX DESIGN FOR NON-MODEL PARAMETERS.

Non-model parameters are criteria used for policy evaluation that are not computed using simulation analysis. Very often the parameters are identified in terms of costs. Examples of evaluation criteria in the category of cost include:

1. Initial costs.
2. Annual operating costs.

Still another type of non-model evaluation criteria exists that is not easily reduced to cash flows. These parameters have to do with improved working conditions (i.e., safety and user acceptance).

To demonstrate the concept of A-matrix construction for non-model parameters an example is presented in Figure 4.6. Note that the two dimensions of importance are:

1. Equipment characteristics (y-axis).
2. Evaluation Criteria (x-axis).

Evaluation criteria categories are common to all policy alternatives. The example A-matrix for the Barcode system indicates the characteristics of the device that should be considered for decision analysis. The portable, lightweight wand should be weighted favorably. Cost, flexibility and safety could also be considered.

With regard to the case study, approximations for initial costs
### Barcode Scanning Device

<table>
<thead>
<tr>
<th>Equipment Parameters</th>
<th>Cost</th>
<th>Flexibility</th>
<th>Safety</th>
<th>User Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wand</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Portable</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Weight</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Memory</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cost</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Evaluation Criteria**

*Figure 4.6. Non-Model Parameter A-Matrix.*
and system flexibility are considered. Following is a brief discussion on measuring non-model parameter values.

4.9 Measurement of Non-model Parameters.

Non-model parameters are defined as parameters that are not computed using simulation or that are not easily reduced to cash flows. Measurement is in terms of scaled values that indicate the relative impact of the parameter within the policy alternative under consideration. For example, to include "system control" in the decision analysis, a value is chosen from the given scale that reflects its rating in this category (i.e., 8). Figure 4.7 is an example of the non-model measurement scale for System Control. This specification procedure is acceptable because of the anchoring step included within the decision model logic. (A detailed discussion of anchoring is found in Section 3.8.1, step 10). While the rating is subjective in nature it does allow non-model parameters that are traditionally excluded from calculations to weigh in the evaluation process. The next section describes in detail the computerized Decision Model that is used to evaluate the policy alternatives of the case study.

4.10 Description of the Decision Model.

This section presents a detailed description of the computerized Decision Model used for material management policy selection. Using BASIC programming language, the constructs of multiattribute preference modeling and the Churchman/Ackoff direct assessment technique are combined to simultaneously evaluate up to 10 policy alternatives with as many as 20 attributes. A flow diagram of the model structure can be
Figure 4.7. Non-model Scale for System Control Parameter.
Initialize

EXECUTION OF PARAMETER RANKINGS
SPECIFY NUMBER OF PARAMETERS
ENTER PARAMETERS IN THEIR PERCEIVED ORDER OF IMPORTANCE
SPECIFY PARAMETER SCALING

CHANGES IF REQUIRED

EXECUTION OF RELATIVE WEIGHT ASSIGNMENTS
INSTRUCTIONS
ASSIGN INDIVIDUAL WEIGHTS
CONSISTANCY CHECK
NORMALIZATION
DISPLAY

CHANGES IF REQUIRED

EXECUTION OF ALTERNATIVE SPECIFICATIONS
ENTER NUMBER OF ALTERNATIVES
ENTER NAME, PARAMETER VALUES
INPUT SUMMARY

CHANGES IF REQUIRED

ANCHORING

OUTPUT SUMMARY
EVALUATION SUMMARY OF ALTERNATIVES SCORES
DETERMINE FINAL SELECTION ALTERNATIVE

Figure 4.8. Flowchart for Decision Model.
found in Figure 4.8.

As illustrated, initialization begins with a brief description of the program function. The monitor screen displays a message stating that execution of the program requires three categories of input:

1. A set of alternatives.
2. Information regarding the performance of the alternatives.
3. Associated preference information for the alternatives.

This message continues, stating that "output for the model is in terms of calculated numerical worths that designate the final selection alternative based on the decision maker's preferences".

Next, specific instructions are presented for using the program algorithm. A display screen indicates that execution begins by entering the parameters in their perceived order of importance. (i.e., let parameter 1 \(P(1)\), represent the most valued, \(P(2)\) the next most valued and \(P(n)\) the least valued. Following these instructions, the number of parameters to be evaluated is input to the model. The number is echoed (reprinted on the screen) to confirm input accuracy. Note that, if the number specified exceeds the parameter limit condition an error message is displayed and the user is prompted to start over. Next, a series of programming loops are executed in the program. These loops contain the logic for the Churchman/Ackoff assessment technique. Here the user must specify the ith parameter and its respective scaling. (Note that "scaling" refers to the preference effect of the performance level, i.e., negative scaling indicates that preferability decreases with increases in the level of
Upon entering the nth parameter into the program, a summary display of input is presented. If changes are required the user specifies the attribute number and modifies the listing accordingly.

Next, instructions are presented for relative weight assignments. The instruction indicates that this phase of the program assigns relative weights to the parameters specified above. The most important parameter is automatically assigned value of 1. The weight of each subsequent parameter must be less than or equal to one and must be less than or equal to the weight of the parameter immediately preceding it. After relative weights are assigned to the parameters, consistency checking is made for each weight entry. If the specified value is too high an error message is displayed stating the degree to which the weight condition has been exceeded and instructs the user to reassign the ith parameter specification. Provided the consistency check is not violated for the nth parameters, a summary display is provided. If changes are required, the user specifies the attribute number(s) and modifies the weight assignment(s) accordingly.

Once ranking and relative weights for the parameters are specified, the program internally normalizes the input. This normalization is the preference weight \( w'_i \) discussed in Section 3.8.1, step 9, regarding value functions.

The next display screen designates execution of alternative specifications. Here the user responds to two questions. The first being to identify the ith policy alternative, the second being to assign values to the parameters previously input to the program.
Following this series of responses and input summary of the list of alternatives is provided. If changes are required, the user specifies the alternative number and modifies the values accordingly. Within this phase of the program, anchoring of the responses occurs.

Internally, each attribute level is compared to a single anchor point (the highest value within the attribute level). As discussed in the literature review (Section 2 on Direct Assessment Methods) the parameter values essentially represent a ratio of the utilities. This fact has significant ramifications for the designation of non model parameter levels (discussed in Section 4.9). This utility is the $x'_i$ variable for the policy alternative.

A value function is computed for each alternative of the form $F = \Sigma w'_i x'_i$ that determines final policy selection. The most preferred alternative is represented by the value function with the highest value. At the end of execution a complete input summary and output is provided in hard copy form.

To make the decision model efficient, effective and "user-friendly" the following design features are incorporated into its execution.

1. Screen Control - Allows the user to minimize built-in-delays for instruction screens.

2. Color Codes - Blue background, White foreground, Black border combination provides high legibility contrast to minimizes stress on the user.

3. Sound Codes - Short "Beep" tones are included to relay the logical progression of the program.
4.11 Summary and Conclusions.

This chapter focused on implementing the Decision Support Algorithm in the case study environment. Four scenarios are outlined for simulation analysis. The first scenario represents the existing operating methods of the MDC, and is considered the standard for alternative policy analysis. The remaining 3 scenarios represent policy alternatives that examine strategically placed material handling equipment into the MDC distribution network. Specifically, Barcode Scanners, Power Driven Carts, and Automatic Storage and Retrieval Systems are examined. Within the framework of each scenario, its purpose, objective, and method of implementation is provided. The later portion of the chapter is devoted to considerations regarding implementation of decision analysis. Special attention is devoted to identifying and measuring non-model parameters. Lastly a description of the Computerized Decision Support System is presented.

Chapter 5 presents the results from the simulation analysis and the final policy selection based on specification of MDC personnel.
CHAPTER 5

EMPIRICAL ANALYSIS USING THE DECISION SUPPORT SYSTEM

The Material Management Decision Support System, formulated in Chapter 3, was utilized to evaluate three policy alternatives in the case study distribution center. The simulated results of the material handling equipment investigated are presented in this chapter. The results are significant because they describe the predicted impact of the alternatives on the distribution system. Favorable increments in system performance measures determine the worthiness of each policy.

To evaluate the policies across the parameters of interest to case study management, the computerized Decision Model was utilized. Installation cost and system flexibility were selected to be the non-model parameters included in the analysis. Lastly, the selected policy alternative is presented along with a discussion regarding value function interpretation.

5.1 Review of Planned Empirical Studies.

To establish a base condition for management policy comparisons, the existing operations of the MDC were analyzed using the simulation model. A detailed description of the simulation design is presented in Section 5.2.

Three material management policies aimed at reducing MDC throughput time were also investigated. 140 hours of simulated run time was used to analyze each policy. This time represents production hours for one month, based on four, 5-day weeks with 7 hours per day.

Two of the four scenarios involved operations outside the
boundaries of the stockroom model designed in this research. The net effect of these policies was determined by variations in performance measures that link the two simulation models. This is accomplished by calculating the total elapsed time from unloading materials on the receiving dock to storage of the materials in the stockroom.

For each policy the relative significance of computed variation in the "Dock to Stock" performance measure is determined from decision analysis (discussed in Section 5.7). Special attention is given to the stockroom model performance measures because the ultimate goal of the three policies is the rapid, controlled movement of materials into and out of this operation upon request.

The first policy alternative investigates implementation of Barcode Scanning Equipment into the material identification operations on the Receiving Dock. This method replaces the present method of opening containers to obtain packing slips that identify materials. The new procedure is assumed to utilize a portable wand device to decode prelabeled barcodes on containers. A detailed description of the BarScan System policy is provided in Section 5.3.

The second policy alternative investigates the combined implementation of Barcode material identification and Power Driven Carts to transport UPS items from the Receiving Operations Drop Area to the Inspection Department. The cart system is investigated to determine the effect on UPS throughput time as a result of having the capability to move several unit loads per move time. The cart system is evaluated in combination with the Barcode system because the
forktruck presently used to move materials is considered adequate if the existing method of material identification is used. A detailed description of the BAR/CART system is provided in Section 5.4.

The third policy alternative considers two material handling systems for the Stockroom Department. For the sake of clarity the individual systems will be considered policy number 3 and 4.

The third policy alternative considers the impact of implementing Carousels into the stockroom processing operations. The Carousel is expected to have the most significant impact on retrieval operations and a reduction in the total time required to process issue transactions is reduced. Simulation design of this policy is found in Section 5.5.

The fourth policy alternative implements Automatic Storage and Retrieval Systems in the stockroom. The ASRS is considered for its order processing flexibility and overall system control. The details of the simulation analysis are found in Section 5.6.

5.2 Simulation Analysis of Present MDC Operations.

This section describes the simulation analysis computed for the present MDC operations. Discussion focuses on material throughput time, resource utilization, and workstation queue lengths. Type B simulation was used for this analysis, thus assuming that stockroom transaction processing occurs on a first-come, first-serve basis with no preempting of resource units. Four categories of SLAM OUTPUT statistics are discussed.

The first category of statistics is for user-defined performance
measures and are based on observations (Table 5.1-A). These performance measures refer to the total time each transaction spends in the distribution system. For example, "UPS TO BIN" values are computed by subtracting the transactions arrival time (dock delivery) from the current time (stockroom bin storage) in the simulation run. The figures indicate that, on average 3.4 days and 12.13 days are required to receive and put-to-stock UPS and Bulk items, respectively. This calculation is performed by dividing the mean value of the performance measure by the number of hours per day in the simulation run.

The average time to process issue transactions is calculated to be 26.50 hours or 3.8 days. Note also that the average time to process backorders is 24.72 hours or 3.5 days. Adding average issue time to the time required to receive and stock materials establishes two measures that approximate material throughput time:

1) Measure 1 = Average time required to receive, stock, and pick only UPS materials.

2) Measure 2 = Average time to receive and stock UPS and Bulk materials plus the time required to pick UPS materials.

For the existing MDC operations measures 1 and 2 for system throughput time are found to be 6.9 days and 19.28 days respectively.

The second category of statistics is the statistics for time persistant variables (Table 5.1-B). In the MDC model these variables act as counters, incrementing by one unit each time a transaction is routed through it's path in the network code. These statistics provide
Table 5.1. Summary SLAM Output Analysis: Base System.

<table>
<thead>
<tr>
<th>Section A: Statistics for Variables Based on Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance Measure</td>
</tr>
<tr>
<td>UPS TO BIN</td>
</tr>
<tr>
<td>BULK TO RACK</td>
</tr>
<tr>
<td>KIT TSYS</td>
</tr>
<tr>
<td>EIR TSYS</td>
</tr>
<tr>
<td>UPR TSYS</td>
</tr>
<tr>
<td>PNP TSYS</td>
</tr>
<tr>
<td>STS TSYS</td>
</tr>
<tr>
<td>BO TSYS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section B: Statistics for Time Persistent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance Measure</td>
</tr>
<tr>
<td>SH.BLK NO</td>
</tr>
<tr>
<td>SRUPS NO</td>
</tr>
<tr>
<td>WSE NO</td>
</tr>
<tr>
<td>ISE NO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section C: File Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>File Number</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>36</td>
</tr>
<tr>
<td>37</td>
</tr>
<tr>
<td>41</td>
</tr>
<tr>
<td>45</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Section D: Resource Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource</td>
</tr>
<tr>
<td>TRUCK</td>
</tr>
<tr>
<td>SPV1B</td>
</tr>
<tr>
<td>CLERK</td>
</tr>
<tr>
<td>SPV2B</td>
</tr>
</tbody>
</table>
excellent checkpoints in the simulation model to verify the number of entities flowing from workstation to workstation. Here, stockroom Bulk/UPS No. signifies the number of orders received into the stockroom from the Inspection Department or internal trucking operations. During the simulated run of 140 hours, 43 Bulk orders and 438 UPS orders were sent to the stockroom.

The Error No. is based on the prespecified percentage (10%) of errors encountered in the stockroom workstations and Inspection stations. Obviously attempts should be made to reduce errors because of their time consuming and costly nature. The Stockroom Model currently detects error transactions after approximately 3 minutes of resource unit utilization. While workstation errors are closely tied to vendor mixups, inspection station errors are more related to order-picking procedures internal to the stockroom. The total number of hours lost to error processing during the simulated time period is found by: Total Hours Lost to Errors = (Total Error Count x 3 min)/60 min. Using this equation, the total number of hours lost to error processing in the stockroom was found to be 15.05 hours/month or 11% of total production time per month.

The third category of statistics is the File or queue statistics. Queue lengths for the operations occurring inside the Stockroom Department are found in Table 5.1-C. Note that the File statistics must be divided by the number of resource units to obtain individual workstation queue lengths. The figures in 5.1-C indicate that items are essentially, processed immediately upon arrival to the receiving
operation in the stockroom. The low values for the Truck, Workstation(s), and Clerk are attributed to the number and arrival rate of items arriving to the stockroom from the Receiving Operations. In contrast, the average queue length for inspection stations is calculated to be 168.4 transactions. The current length column for this statistic indicates the status of workstation queue lengths at the end of the simulation run. Dividing this statistic by the number of resource units indicates that approximately 367 transactions await issue processing per inspection station after 140 hours of simulated time. Note that the workstation queue lengths are typically used to determine layout requirements to accommodate queue lengths and to pace the utilization of the resource unit. Note also that the average waiting time applies to all workstations and is not divided by resource units. The average waiting time for issues is 26.92 hours or 3.8 days.

The fourth category of statistics is the Resource statistics (Table 5.1-D). The figures in the Maximum utilization column indicate that all service units were utilized at some point during the simulation run. The utilization figures for the clerk and truck resource units suggest that one operator may perform these operations. Consistent with the file length information, the inspection stations in the stockroom are fully utilized. Comparing this utilization with that of the workstations, a strong argument can be made to reallocate one service unit from stocking to retrieval operations.

In summary, the stockroom has sufficient resources on the
receiving end of the operation to accommodate the incoming work load. The inspection operations of the stockroom represent a bottleneck for UPS material throughput. Also, a considerable amount of work time is lost to error processing. Throughput time for UPS and combined materials was found to be 7 and 19 days, respectively.

Note: To examine the effect of operator utilization and system throughput, the stockroom workstation and inspection station operations are reallocated resource units of 2 and 4 respectively. Full consideration of this reallocation is accounted for in the forthcoming decision analysis.

5.3 Simulation of Barcode System.

The simulated results for implementing the Barcode system are presented in Table 5.2. Discussion focuses on material throughput time, resource utilization and workstation queue lengths as affected by policy implementation. Type B simulation was used for the analysis. One clerk resource unit, two workstation resource units, and four inspection station resource units comprise new manpower allocation in the stockroom.

The performance measures revealing the effect of implementing the Barscan system are: UPS TO BIN and BLK TO RACK. The mean value computed for UPS to BIN equals 7.14 hours, signifying a net reduction of 16.22 hours \((23.36 - 7.14)\) in the average time to receive and stock UPS materials. The mean value computed for BULK TO RACK equals 3.28 hours, signifying a net reduction of 81.66 hours \((84.94 - 3.28)\) in the average time to receive and shelve BULK materials. The figures
Table 5.2. Summary SLAM Output Analysis: Barcode System.

### Section A: Statistics for Variables Based on Observation

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Mean Value</th>
<th>Standard Deviation</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Number of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPS TO BIN</td>
<td>7.14</td>
<td>19.11</td>
<td>0.76</td>
<td>107.6</td>
<td>157</td>
</tr>
<tr>
<td>BULK TO RACK</td>
<td>3.28</td>
<td>1.41</td>
<td>1.26</td>
<td>8.43</td>
<td>277</td>
</tr>
<tr>
<td>KIT TSYS</td>
<td>13.16</td>
<td>6.97</td>
<td>1.0</td>
<td>25.05</td>
<td>344</td>
</tr>
<tr>
<td>EIR TSYS</td>
<td>12.61</td>
<td>7.11</td>
<td>0.36</td>
<td>24.35</td>
<td>113</td>
</tr>
<tr>
<td>UPR TSYS</td>
<td>12.17</td>
<td>7.04</td>
<td>0.08</td>
<td>24.32</td>
<td>1042</td>
</tr>
<tr>
<td>PNP TSYS</td>
<td>12.07</td>
<td>6.98</td>
<td>0.075</td>
<td>24.33</td>
<td>396</td>
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<tr>
<td>STS TSYS</td>
<td>11.96</td>
<td>7.53</td>
<td>0.40</td>
<td>23.79</td>
<td>29</td>
</tr>
<tr>
<td>BO TSYS</td>
<td>11.59</td>
<td>7.19</td>
<td>0.33</td>
<td>24.46</td>
<td>30</td>
</tr>
</tbody>
</table>

### Section B: Statistics for Time Persistent Variables

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Mean Value</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Time Interval</th>
<th>Current Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRBLK NO</td>
<td>136.18</td>
<td>0.0</td>
<td>277.0</td>
<td>140.0</td>
<td>277.0</td>
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<tr>
<td>SRUPS NO</td>
<td>90.77</td>
<td>0.0</td>
<td>187.0</td>
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<td>187.0</td>
</tr>
<tr>
<td>WSE NO</td>
<td>18.05</td>
<td>0.0</td>
<td>40.0</td>
<td>140.0</td>
<td>40.0</td>
</tr>
<tr>
<td>ISE NO</td>
<td>135.5</td>
<td>0.0</td>
<td>279.0</td>
<td>140.0</td>
<td>279.0</td>
</tr>
</tbody>
</table>

### Section C: File Statistics

<table>
<thead>
<tr>
<th>File Number</th>
<th>Workcenter</th>
<th>Average Length</th>
<th>Maximum Length</th>
<th>Current Length</th>
<th>Average Waiting Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>SR Hold</td>
<td>0.0</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>36</td>
<td>TRUCK</td>
<td>0.1914</td>
<td>4</td>
<td>0</td>
<td>0.0967</td>
</tr>
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<td>37</td>
<td>WS</td>
<td>0.0125</td>
<td>3</td>
<td>0</td>
<td>0.0022</td>
</tr>
<tr>
<td>41</td>
<td>CLERK</td>
<td>0.0</td>
<td>1</td>
<td>0</td>
<td>0.0</td>
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<td>45</td>
<td>IS</td>
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<td>461</td>
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### Section D: Resource Statistics

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<th>Average Utilization</th>
<th>Maximum Utilization</th>
<th>Current Utilization</th>
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</thead>
<tbody>
<tr>
<td>TRUCK</td>
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<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SPV1B</td>
<td>2</td>
<td>0.502</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>CLERK</td>
<td>1</td>
<td>0.038</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SPV2B</td>
<td>4</td>
<td>3.998</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
indicate that, on average 1 day and 1/2 day are required to receive and put-to-stock UPS and Bulk items, respectively under the new policy. The average time to process issue transactions are calculated to be 12.142 hours or 1.73 days. And, the average time that Backorder transactions spent in the distribution process was 11.59 hours or 1.66 days. The figures reveal the impact of reassigning resource units to the inspection station operations to result in a 14.58 hour (2.1 day) reduction in the average issue time and an 13.15 hour (1.87 day) reduction in the time Backorder transactions spend in the system.

The two measures of throughput time for the Barcode policy are calculated to be:

Measure 1: (UPS throughput) = 7.14 hrs. + 12.142 hrs. = 19.3 hrs.  
= 2.75 days

Measure 2: (UPS/BULK throughput) = ((7.14 + 3.28 hrs.)/2) + 12.142  
= 17.35 hrs.  
= 2.48 days

The reduction in measure 1 and measure 2 throughput time in comparison to the BASE operations is 4.15 days and 16.8 days, respectively.

These figures draw attention to three points:

1. The substantial reduction in performance measures suggest that the existing material receiving and document control operations are a major bottleneck in the distribution operations.

2. Simulated results of the Barcode system policy suggests that the concept of implementing barscanning equipment can enhance
the operations of the MDC with respect to material throughput time.

3. The degree of enhancement to the receiving operation actually realized is a function of:

(A) Original simulation design of the operations under investigation.

(B) Appropriateness of the design and activity durations used to represent the new policy.

Statistics for time persistent variables show that, 464 orders were received into the stockroom and that 319 error transactions were processed for the Barscan policy. These figures showed no substantial variation as totals but reflect different distributions of order types arriving to the stockroom.

File statistics for the Barcode system show no significant queue lengths for the truck, workstation or clerk operations. The average queue length for the stockroom inspection was found to be 57.39 transactions and the current length for each inspection station at the end of the simulation run was 115.25. Therefore, it can be concluded that the additional resource in inspection stations reduced average issue time by 2 days and reduced queue lengths per workstation by approximately 91 transactions.

Resource statistics for the policy indicate increased utilization of trucks resulting from the number of BULK arrivals to the stockroom. As expected from the file information, inspection station resource units are fully utilized during the simulation run.
In summary, the policy investigating Barcode equipment is predicted to enhance material identification operations. Simulation results suggest that the time required to receive and stock materials can be reduced to 1 day. Also, assigning one additional resource unit to the inspection station operations reduced average inspection time to approximately 2 days. Throughput time for UPS and combined materials was found to be between 2 and 3 days for both measures.

5.4 Simulation of Barcode/Power Driven Cart Combination.

The simulated results for implementing the combined material-identification, material-transport policy are presented in Table 5.3. Discussion focuses on variations to policy 5.3 output analysis as a result of implementing power driven carts to transport UPS materials to the stockroom. Here, primary attention is given to the performance measures that link the models in terms of increments in the time required to receive materials into the stockroom and on the number of arrivals occurring to the stockroom as a result using multiple cart transport. Type B simulation was used for the analysis.

The performance measure revealing the effect of implementing Power-Driven-Carts in the receiving operations is "UPS TO BIN". The mean value for this parameter is 6.30, indicating a reduction of approximately one hour in the time required to receive UPS materials to stock. The number of UPS orders arriving to the stockroom totaled 211 reflecting an increase of 24 orders. These additional orders did not significantly change workstation utilization which remained at 50%.

In summary, simulation of Barcode-Powered Driven Cart System
Table 5.3. Summary SLAM Output Analysis: Barcode/Cart System.

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Mean Value</th>
<th>Standard Deviation</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Number of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPS TO BIN</td>
<td>6.30</td>
<td>14.78</td>
<td>0.798</td>
<td>105.5</td>
<td>196</td>
</tr>
<tr>
<td>BULK TO RACK</td>
<td>3.85</td>
<td>1.80</td>
<td>1.35</td>
<td>9.74</td>
<td>300</td>
</tr>
<tr>
<td>KIT TSYS</td>
<td>13.23</td>
<td>7.12</td>
<td>1.0</td>
<td>25.30</td>
<td>345</td>
</tr>
<tr>
<td>EIR TSYS</td>
<td>12.49</td>
<td>7.19</td>
<td>0.36</td>
<td>24.52</td>
<td>116</td>
</tr>
<tr>
<td>UPR TSYS</td>
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<td>7.04</td>
<td>0.08</td>
<td>24.48</td>
<td>1043</td>
</tr>
<tr>
<td>PNP TSYS</td>
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<td>7.11</td>
<td>0.075</td>
<td>24.47</td>
<td>401</td>
</tr>
<tr>
<td>STS TSYS</td>
<td>12.07</td>
<td>6.60</td>
<td>0.400</td>
<td>22.82</td>
<td>29</td>
</tr>
<tr>
<td>BO TSYS</td>
<td>12.23</td>
<td>7.19</td>
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<table>
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<th>Current Value</th>
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<tr>
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</tr>
<tr>
<td>WSE NO</td>
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<td>34.0</td>
</tr>
<tr>
<td>ISE NO</td>
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<td>140.0</td>
<td>268.0</td>
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</table>

<table>
<thead>
<tr>
<th>File Number</th>
<th>Workcenter</th>
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<th>Current Length</th>
<th>Average Waiting Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>SR Hold</td>
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<td>0</td>
</tr>
<tr>
<td>36</td>
<td>TRUCK</td>
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<td>6</td>
<td>0.1317</td>
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<tr>
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<td>0.0022</td>
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<td>0</td>
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<th>Current Utilization</th>
</tr>
</thead>
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<td>TRUCK</td>
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<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SPV1B</td>
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<td>0.5169</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>CLERK</td>
<td>1</td>
<td>0.0251</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SPV2B</td>
<td>4</td>
<td>3.99</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
predicted a one hour reduction to the stand alone Barscan System.

5.5 Simulation of the Carousel System.

The simulated results from implementing carousel equipment into the stockroom is presented in Table 5.4. Discussion focuses on material retrieval time for the inspection station operations. The performance measure revealing the effect of implementing the carousel system is: Issue-transaction Time in System. Type B simulation was used for this case.

The average issue time for transactions after implementing the carousel system is computed to be .3088. The new Back Order time in system is given by .2878. These figures indicate a 25.69 and 24.45 hour reduction in average issue transaction time and Back Order time in system respectively. Note that the reduction in transaction processing time had a very significant effect on the average length of inspection station queue lengths and resource unit utilization. The average length of the queue was reduced to less than one transaction with only 2 transactions remaining to be processed at the end of the simulation run. The computed figure for average resource unit utilization is 0.901. These figures appear reasonable for real life workload conditions.

In summary, the reduction in issue transaction duration attributed to implementing carousel equipment is predicted to considerably enhance inspection station operations in the stockroom. Resource utilization, and queue lengths per inspection station are eliminated as bottlenecks in the distribution network. Throughput measures for the new system
Table 5.4. Summary SLAM Output Analysis: Carousel System.

Section A: Statistics for Variables Based on Observation

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean Value</th>
<th>Standard Deviation</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Number of Observations</th>
</tr>
</thead>
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<td>BULK TO RACK</td>
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<td>2.176</td>
<td>93.47</td>
<td>22</td>
</tr>
<tr>
<td>KIT TSYS</td>
<td>0.7812</td>
<td>0.0496</td>
<td>0.750</td>
<td>0.966</td>
<td>407</td>
</tr>
<tr>
<td>EIR TSYS</td>
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<td>0.270</td>
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</tr>
<tr>
<td>UPR TSYS</td>
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<td>0.060</td>
<td>0.393</td>
<td>1271</td>
</tr>
<tr>
<td>PNP TSYS</td>
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<td>0.0623</td>
<td>0.056</td>
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</tr>
<tr>
<td>STS TSYS</td>
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<td>0.0400</td>
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<td>BO TSYS</td>
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Section B: Statistics for Time Persistent Variables

<table>
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<th>Measure</th>
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<th>Maximum Value</th>
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<th>Current Value</th>
</tr>
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<td>266.0</td>
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Section C: File Statistics

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<th>Maximum Length</th>
<th>Current Length</th>
<th>Average Waiting Time</th>
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</thead>
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<tr>
<td>35</td>
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<td>0.0</td>
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<td>37</td>
<td>WS</td>
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<td>41</td>
<td>CLERK</td>
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<td>IS</td>
<td>0.7574</td>
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<td>0.0401</td>
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</table>

Section D: Resource Statistics

<table>
<thead>
<tr>
<th>Resource</th>
<th>Current Capacity</th>
<th>Average Utilization</th>
<th>Maximum Utilization</th>
<th>Current Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRUCK</td>
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<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SPV1B</td>
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<td>2</td>
<td>1</td>
</tr>
<tr>
<td>CLERK</td>
<td>1</td>
<td>0.0466</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SPV2B</td>
<td>4</td>
<td>3.6043</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
are obtained by adding the figures for the existing receiving operations since changes are only introduced in the retrieval operations of the network. Therefore, carousel throughput (UPS)\[= 3.8 \text{ days + } 0.044 \text{ days} = 3.84 \text{ days.}\]

5.6 **Simulation of the Automatic Storage and Retrieval System.**

The simulated results from implementing ASRS equipment in the stockroom is presented in Table 5.5. Discussion focuses on the material retrieval time for the inspection station operations. The performance measures revealing the effect of implementing the ASRS is:

- **Issue-transaction Time in System.** Type B simulation was used for the simulation.

The average issue time for transactions after implementing ASRS was computed to be .229 hours or 14 minutes. This figure represents a 26.27 and .0798 hour reduction in transaction processing time under the existing operations and the carousel system respectively. The average resource utilization is computed to be .74. This figure suggests that fewer resource units may be required for inspection station processing if ASRS is implemented.

In summary, the simulated results of the policy to implement ASRS predict a reduction in average issue time by as much as 4 days. Resource utilization figures for the policy also suggest a reduction in the number of inspection stations required to adequately handle the workload. Throughput measures for the new system are obtained by adding the figures for the existing receiving operations since changes are only introduced in the retrieval operations of the network.
Table 5.5. Summary SLAM Output Analysis: ASRS System.

<table>
<thead>
<tr>
<th>Section A: Statistics for Variables Based on Observation</th>
<th></th>
</tr>
</thead>
<tbody>
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</tr>
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</tr>
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</table>

<table>
<thead>
<tr>
<th>Section B: Statistics for Time Persistent Variables</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>Mean Value</td>
</tr>
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</tr>
<tr>
<td>SKUPS NO</td>
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<tr>
<td>WSE NO</td>
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</table>

<table>
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<th>Section C: File Statistics</th>
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</tr>
</thead>
<tbody>
<tr>
<td>File Number</td>
<td>Workcenter</td>
</tr>
<tr>
<td>35</td>
<td>SR Hold</td>
</tr>
<tr>
<td>36</td>
<td>TRUCK</td>
</tr>
<tr>
<td>37</td>
<td>WS</td>
</tr>
<tr>
<td>41</td>
<td>CLERK</td>
</tr>
<tr>
<td>45</td>
<td>IS</td>
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</table>

<table>
<thead>
<tr>
<th>Section D: Resource Statistics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource</td>
<td>Current Capacity</td>
</tr>
<tr>
<td>TRUCK</td>
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</tr>
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<td>SPV1B</td>
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<tr>
<td>CLERK</td>
<td>1</td>
</tr>
<tr>
<td>SPV2B</td>
<td>4</td>
</tr>
</tbody>
</table>
Therefore, ASRS throughput = 3.8 days + .03 days = 3.83 days.

5.7 Demonstration of Type A Simulation.

To demonstrate the capabilities of Type A simulation, Back Order transactions were prioritized under the ASRS configuration in the stockroom. The simulated results of this processing capability is presented in Table 5.6. Note that the average issue transaction time in system is computed to be .3826 hours which exceeds the ordinary processing time for ASRS by .1537 hours or 9.2 minutes. However, the average time Back Orders spent in the system is .1577 compared to .1916 for ordinary processing, a difference of .0339 hours or 2 minutes.

In summary, all policies investigated using simulation analysis were predicted to enhance the operating levels of the distribution system. From the experimental analysis, MDC throughput time is reduced from 7 to 20 days to approximately 3 days.

5.8 Analysis Using the Decision Model.

The computerized Decision Model was utilized to evaluate the simulated material management policies. The primary steps required to use the analysis tool are described in this section as well as the presentation of the case study results. Note that case study management is considered the "user" in this analysis. The description of input follows the sequence of operations designed into the program software.

The first step required the determination of decision criteria upon which evaluation would be made. The simulation model performance measures chosen for decision criteria were:
Table 5.6. Summary SLAM Output Analysis: Backorder Prioritization.

### Section A: Statistics for Variables Based on Observation

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Mean Value</th>
<th>Standard Deviation</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Number of Observations</th>
</tr>
</thead>
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<td>132</td>
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### Section B: Statistics for Time Persistent Variables

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<tr>
<th>Performance Measure</th>
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<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Time Interval</th>
<th>Current Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSE NO</td>
<td>15.30</td>
<td>0.0</td>
<td>36.0</td>
<td>140.0</td>
<td>36.0</td>
</tr>
<tr>
<td>ISE NO</td>
<td>123.3</td>
<td>0.0</td>
<td>261.0</td>
<td>140.0</td>
<td>261.0</td>
</tr>
</tbody>
</table>

### Section C: File Statistics

<table>
<thead>
<tr>
<th>File Number</th>
<th>Workcenter</th>
<th>Average Length</th>
<th>Maximum Length</th>
<th>Current Average Length</th>
<th>Current Waiting Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>CLERK</td>
<td>0.0003</td>
<td>1</td>
<td>0</td>
<td>0.0008</td>
</tr>
<tr>
<td>45</td>
<td>IS</td>
<td>0.0003</td>
<td>5</td>
<td>1</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Section D: Resource Statistics

<table>
<thead>
<tr>
<th>Resource</th>
<th>Current Capacity</th>
<th>Average Utilization</th>
<th>Maximum Utilization</th>
<th>Current Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>1</td>
<td>0.7550</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>0.6961</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>0.7357</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>0.8060</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
1. Average Issue Time.
2. Backorder Time in System.
4. UPS to Rack Time.

Next, consideration was given to non-model parameters and two were selected:

1. Initial Costs.
2. System Flexibility.

Initial costs were obtained from Chapter 2 and MDC management. These costs represent approximations to the amount of expenditure required to buy and install the equipment. Computations are provided for policy installation costs in Table 5.7.

System flexibility is defined as the number of alternative operations, paths or work assignments associated with a particular policy. The scale, for system flexibility varies from 1 to 10, with 10 representing the most favorable value.

Next, the six parameters were rank ordered in their perceived order of importance.

\( P(1) = \text{Cost.} \)

\( P(2) = \text{B.O. Time in System.} \)

\( P(3) = \text{UPS TO BIN.} \)

\( P(4) = \text{BULK TO RACK.} \)

\( P(5) = \text{Avg. Issue Time.} \)

\( P(6) = \text{System Flexability.} \)

After the parameters are rank ordered, relative weights are assigned.
Table 5.7. Initial Cost: Material Management Policies.

<table>
<thead>
<tr>
<th>Policy</th>
<th>Initial Costs Computations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>N/A</td>
</tr>
</tbody>
</table>

- **Policy: Barcode System**
  Initial Costs Computations [15]:
  
  1 computer control device = $10,000  
  + 5 Portable-Hand Held Barscanners (@ 3000.00) = $15,000  
  Total Initial Cost $25,000

- **Policy: Barcode/Power Cart System**
  Initial Costs Computations [15]:
  
  1 Power Device = $23,000  
  + 4 Carts (@ $500.00) = $2,000  
  + 1 Barcode System = $25,000  
  Total Initial Cost $50,000

- **Policy: Carousel System**
  Initial Costs Computations [50]:
  
  15 Carousels (@ 25,000) = $375,000  
  Total Initial Costs $375,000

- **Policy: Automatic Storage and Retrieval System**
  Initial Costs Computations [50]:
  
  1 Storage Machine  
  height < 35 ft. = $21,000/machine  
  7 x load < 1000 lb. = $21,000/machine  
  Central Control logic = $84,000/machine  
  $126,000/machine  
  Total Initial Costs $882,000
assigned. The weight assignments were specified as follows:

Cost = 1.0
B.O. Time in System = .75
UPS TO BIN = .6
BULK TO RACK = .5
Avg. Issue Time = .3
System Flexibility = .25

The number of alternatives to be evaluated was then input to the program. N = 6.

Note: 1 Base Condition of 3 workstations+3 inspection stations in S.R.
1 Base Condition of 2 workstations+4 inspection stations in S.R.
4 Material Handling Alternatives
6 Alternatives

Note: A complete listing of all input is contained in Table 5.8.

The impact of each parameter to the total value function is found by normalizing the parameter weights as shown below:

\[
1 + .75 + .6 + .5 + .3 + .25 = 3.35
\]

Costs: \( \frac{1}{3.35} = .298 \) B.O. TSYS: \( \frac{.75}{3.35} = .223 \) UPS TO BIN: \( \frac{.6}{3.35} = 0.179 \)

BULK TO RACK: \( \frac{.5}{3.35} = .149 \) AVG. ISSUE TIME: \( \frac{.3}{3.35} = .089 \)

SYSTEM FLEXIBILITY: \( \frac{.25}{3.35} = .07 \)

The value function is given by:

\[
F(x) = -.30(x_1) - .22(x_2) - .18(x_3) = .15(x_4) - .09(x_5) + .07(x_6)
\]

In general the value function represents the situation where costs \([- .30(x_1)]\) can be offset by favorable changes in the distribution
<table>
<thead>
<tr>
<th>Policy Alternatives</th>
<th>Cost</th>
<th>Back Order Time in System</th>
<th>UPS TO BIN</th>
<th>BULK TO RACK</th>
<th>Average Issue Time</th>
<th>System Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>0</td>
<td>24.47</td>
<td>23.36</td>
<td>84.94</td>
<td>26.5</td>
<td>5</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>0.75</td>
<td>0.6</td>
<td>0.5</td>
<td>0.3</td>
<td>0.25</td>
</tr>
<tr>
<td>Scaling</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Barcode System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>25000</td>
<td>11.59</td>
<td>7.14</td>
<td>3.28</td>
<td>12.26</td>
<td>7</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>0.75</td>
<td>0.6</td>
<td>0.5</td>
<td>0.3</td>
<td>0.25</td>
</tr>
<tr>
<td>Scaling</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Bar/Cart</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>50000</td>
<td>12.23</td>
<td>6.30</td>
<td>3.852</td>
<td>12.408</td>
<td>7.5</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>0.75</td>
<td>0.6</td>
<td>0.5</td>
<td>0.3</td>
<td>0.25</td>
</tr>
<tr>
<td>Scaling</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Carousel System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>375000</td>
<td>0.2878</td>
<td>11.88</td>
<td>33.85</td>
<td>0.308</td>
<td>5</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>0.75</td>
<td>0.6</td>
<td>0.5</td>
<td>0.3</td>
<td>0.25</td>
</tr>
<tr>
<td>Scaling</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Automatic Storage and Retrieval System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>882000</td>
<td>0.1961</td>
<td>11.87</td>
<td>33.85</td>
<td>0.2296</td>
<td>8</td>
</tr>
<tr>
<td>Weight</td>
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<td>0.75</td>
<td>0.6</td>
<td>0.5</td>
<td>0.3</td>
<td>0.25</td>
</tr>
<tr>
<td>Scaling</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
</tr>
</tbody>
</table>
system \[-.22(x_2) - .18(x_3) - .15(x_4) - .09(x_5)\] and flexibility [+0.07(x_6)] can contribute to the policy selection if costs and performance level impacts are close.

The value function computed for each alternative is as follows:

- \(\text{BASE(3/3)} = -.586\)
- \(\text{BASE(2/4)} = -.285\)
- \(\text{BARCODE SYSTEM} = -.149\)
- \(\text{BAR/CART SYSTEM} = -.154\)
- \(\text{CAROUSEL SYSTEM} = -.23\)
- \(\text{ASRS} = -.371\)

The final policy selection, based on user preferences, is the BARCODE SYSTEM. This selection is based on the simultaneous reduction to Receiving and Stocking performance measures computed for the policy (recall that 4 Inspection Resource units were allocated for this policy). The general relationship captured in this application can be stated: For negatively scaled parameters, the lower the computed input value, the least negative effect to the total value function.

Lastly, the value function provides a rank ordering of the alternatives based on user preferences. That is, the policy with the higher value function indicates greater user preferences. The rank of the case study alternatives were found to be:

<table>
<thead>
<tr>
<th>Policy Rank</th>
<th>Policy</th>
<th>Value Function Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>Barcode System</td>
<td>-.149</td>
</tr>
<tr>
<td>2nd</td>
<td>Bar/Cart System</td>
<td>-.153</td>
</tr>
</tbody>
</table>
3rd - Carousel System  - .231
4th - Present Operation (2/4)  - .281
5th - Automatic Storage and Retrieval System  - .371
6th - Present Operation (3/3)  - .586

This ranking indicates that the additional cost incurred for the BARSCAN/CART SYSTEM combination is not offset by the 1 hour reduction in the policy performance measure.

Summarizing, the rank order of alternatives based on user preference was found to be:

1st - Barcode System
2nd - Bar/Cart System
3rd - Carousel System
4th - Present Operation (2/4)
5th - Automatic Storage and Retrieval
6th - Present Operation (3/3)

Thus, each of the simulated alternatives to the present system would be preferable to the base case given the cost estimates, simulation results, and decision model parameters assumed. In a given situation, a user may find perturbation of these values to determine their sensitivity of results a useful application of the Decision Support System.
6.1 Summary and Conclusions.

This research has focused on the development of a Material Management Decision Support System. The purpose of the system is to enhance the user's capability to investigate alternative material management policies and evaluate the relative performance of each distribution system.

SLAM simulation language was adopted to model the operating characteristics of a case study Materials Distribution Center. The model was used to predict the impact of installing material handling equipment in three areas of the distribution network. Although the data used for processing durations in the simulations is not based on a formal data collection program, most values seem to be reasonable approximations to actual operating methods. Note, however, that the one-to-one assumption made concerning the number of stockroom transactions per Purchase Order in the Receiving Operations is questionable. While based on the recommendation of case study personnel, this assumption has significant impact on the performance levels that linked the two simulation models. The result of the study are summarized below.

Barcode Scanning Systems were found to have a significant impact on the material identification operation in the Receiving Dock Area, predicting a reduction in receiving throughput time from 3.4 days to 1 day for UPS materials. Power Driven Carts were investigated in
combination with the Barscan System, but this combination was found not to significantly reduce throughput measures. However, a scheduling mechanism designed into the network code to represent resource unit availability indicated that the responsibility of moving materials from the UPS Dock Hold Area to the Inspection Department Drop Area requires one-half or fewer resource units.

The implementation of alternative storage and retrieval methods in the Stockroom Department predicted substantial reductions in average queue length and transaction time for issue operations. Figures also suggested that fewer resource units would be required for the retrieval operations.

The Stockroom model responded as expected to parameter changes for both Type A and Type B code orientations. While not used extensively during the case study, the generic capability of Type A code is significant. The modeling orientation is included because work scheduling and transaction prioritization is a common requirement of stockroom operations.

BASIC programming language was utilized to develop a Decision Analysis software program. The case study value function analyzed using the program was of the form:

\[ F(x) = - \text{Cost}(x) - \sum_{i} \text{Simulation} \left( x_{i+1} - x_{i-1} \right) + \sum_{i} \text{System} \left( x_{i} \right) \]

\[ \text{Performance} \quad \text{Flexibility} \quad \text{Measures} \]

The material handling policies plus the existing operating methods were evaluated using the model. The Barscan system policy was selected as the final alternative based on management preferences implied in the
use of hypothetical input data. The concept of using the decision model in the evaluation of alternatives was received favorably by management with the firm sponsoring the research described in this thesis.

6.2 Recommendations.

The ability of the process-orientation of SLAM to respond to the macro-level design requirements of the distribution system was more than adequate. However, if more detailed modeling of material handling equipment is required the designer should expect to use the combined discrete event-process orientation of the language or explore a more specialized language like SIMAN.

With regard to the case study environment, management is advised to use the processing capabilities of Type A and Type B code in the stockroom model to schedule KIT processing, Backorder Processing and to determine the appropriate allocation of resource units for workstations. Also, some formal ongoing data collection program would further validate the model.

Regarding the Decision Model, analysis can be extended into micro-level phases of evaluating management policies. For example, the selection of a particular Barcode System can be investigated. Decision parameters in this instance might include hand-held fixed and moving-beam scanners versus stationary fixed and moving beam scanners, etc.

Further research utilizing SLAM simulation to characterize general material flow systems is seen as an extension to this modeling effort.
In addition, similar research in the case study environment involving multiple material types that must be processed through some flow of MDC workcenters is seen as useful towards more extensive examination of the simulation model. Research in this area might involve statistical testing on simulated output to formulate confidence intervals regarding model performance. This analysis would be based on stochastic processing durations for material types input to the distribution system. The simulation analysis from variable input can also be used as sensitivity analysis data for the Decision Model value function calculations. Also, a more detailed analysis of decision parameter determination warrants investigation. This study would examine policy selection based on combinations of model and non-model parameters not considered in this research.
REFERENCES


APPENDIX A: MATERIAL MANAGEMENT DECISION MODEL

Detailed User's Guide and Code Listings
ABSTRACT

This user's manual is intended to describe a computerized decision support model developed to analyze multiattribute material management policies.
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<td>A.3.1 Listing of Decision Model Output</td>
<td>179</td>
</tr>
</tbody>
</table>
A.1.0 Introduction.

This manual presents a description of the Material Management Decision Model. The model is based on multiattribute value theory and is designed to enhance the evaluation phase of material management policy selection. The following sections contain information on model execution and non-model parameter measurement. The sourcecode and output analysis for the model are also provided.

A.1.1 Measurement of Non-model Parameters.

Non-model parameters are defined as parameters that are not computed using simulation or that are not easily reduced to cash flows. Measurement is in terms of scaled values that indicate the relative impact of the parameter within the policy alternative under consideration. For example, to include "system control" in the decision analysis, a value is chosen from the given scale that reflects its rating in this category (i.e., 8). Figure 1.1 is an example of the non-model measurement scale for System Control. This specification procedure is acceptable because of the anchoring step included within the decision model logic. While the rating is subjective in nature it does allow non-model parameters that are traditionally excluded from calculations to weigh in the evaluation process. The next section describes in detail the computerized Decision Model that is used to evaluate the policy alternatives.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low</th>
<th>Indifferent</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of</td>
<td>1</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Relative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Importance</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1.1. Non-model Scale for System Control Parameter.
A.2.0 Description of the Decision Model and Instructions for Use.

This section presents a detailed description of the computerized Decision Model used for material management policy selection. Using BASIC programming language, the constructs of multiattribute preference modeling and the Churchman/Ackoff direct assessment technique are combined to simultaneously evaluate up to 10 policy alternatives with as many as 20 attributes. A flow diagram of the model structure can be found in Figure 1.2.

A.2.1 Executing the Decision Model.

The following steps are required to execute the computerized Decision Model. Instructions appear in this section as they appear on the monitor display for the software. The dual diskette drive IBM Personal Computer (PC) is considered the system hardware in this instruction set.

Step 1: Insert the "DOS" diskette into drive A and insert the Decision Model diskette into drive B of PC. Turn on the drive system and the system monitor.

Step 2: Press "RETURN" until the "A>" sign appears on the monitor.

Step 3: Type "BASICA". The operating system is now in basic programming language.

Step 4: Type "LOAD B: MMM". This command loads the decision model file. B represents the drive mechanism and "MMM" is the filename given to the software (Material Management Model).

Step 5: Type "RUN" or use the PF3 Key to execute the program.

Step 6: Initialization begins with a brief description of the program
Figure 1.2. Flowchart for Decision Model.
function. The monitor screen displays a message stating that execution of the program requires three categories of input:

1. A set of alternatives.

2. Information regarding the performance of the alternatives.

3. Associated preference information for the alternatives.

This message continues, stating that "output for the model is in terms of calculated numerical worths that designate the final selection alternative based on the decision maker's preferences".

Step 7: Next, specific instructions are presented for using the program algorithm. A display screen indicates that execution begins by entering the parameters in their perceived order of importance. (i.e., let parameter 1 P(1), represent the most valued, P(2) the next most valued and P(n) the least valued.

Following these instructions, the number of parameters to be evaluated is input to the model. The number is echoed (reprinted on the screen) to confirm input accuracy. Note that, if the number specified exceeds the parameter limit condition an error message is displayed and the user is prompted to start over.

Step 8: Next, a series of programming loops are executed in the program. These loops contain the logic for the Churchman/Ackoff assessment technique. Here the user must
specify the ith parameter and its respective scaling. (Note that "scaling" refers to the preference effect of the performance level, i.e., negative scaling indicates that preferability decreases with increases in the level of that measure.) Upon entering the nth parameter into the program, a summary display of input is presented. If changes are required the user specifies the attribute number and modifies the listing accordingly.

Step 9: Next, instructions are presented for relative weight assignments. The instruction indicates that this phase of the program assigns relative weights to the parameters specified above. The most important parameter is automatically assigned value of 1. The weight of each subsequent parameter must be less than or equal to one and must be less than or equal to the weight of the parameter immediately preceding it. After relative weights are assigned to the parameters, consistency checking is made for each weight entry. If the specified value is too high an error message is displayed stating the degree to which the weight condition has been exceeded and instructs the user to reassign the ith parameter specification. Provided the consistency check is not violated for the nth parameters, a summary display is provided. If changes are required, the user specifies the attribute number(s) and modifies the weight assignment(s) accordingly. Once ranking and relative
weights for the parameters are specified, the program internally normalizes the input.

Step 10: The next display screen designates execution of alternative specifications. Here the user responds to two questions. The first being to identify the $i$th policy alternative, the second being to assign values to the parameters previously input to the program. Following this series of responses and input summary of the list of alternatives is provided. If changes are required, the user specifies the alternative number and modifies the values accordingly. Within this phase of the program, anchoring of the responses occurs.

Internally, each attribute level is compared to a single anchor point (the highest value within the attribute level). The parameter values essentially represent a ratio of the utilities. This fact has significant ramifications for the designation of non-model parameter levels (discussed in Section 1.1). This utility is the $x'_i$ variable for the policy alternative.

A value function is computed for each alternative of the form $F = \sum_{\parallel i} w'_i x'_i$ that determines final policy selection. The most preferred alternative is represented by the value function with the highest value.

Step 11: Hard copies of the Decision Analysis are obtained by using the "CNTL" "Prt" keyboard command.

To make the decision model efficient, effective and "user-friendly" the following design features are incorporated into its execution:
1. Screen Control - Allows the user to minimize built-in-delays for instruction screens.

2. Color Codes - Blue background, White foreground, Black border combination provides high legibility contrast to minimize stress on the user.

3. Sound Codes - Short "Beep" tones are included to relay the logical progression of the program.
A.3.0 Listing of Decision Model Sourcecode.

1 COLOR 7,1,0:CLS
2 PRINT:PRINT
10 PRINT "MATERIAL MANAGEMENT DECISION SUPPORT MODEL"
11 PRINT "-------------------------------------------------------------
20 PRINT "PROGRAM DESIGNER: DARRELL A. DAVIS"
21 PRINT "IEOR DEPT. V P I & S U"
29 PRINT ""
30 PRINT" THIS PROGRAM IS DESIGNED TO EVALUATE ALTERNATIVE MATERIAL"
31 PRINT ""
40 PRINT " DISTRIBUTION METHODS. EXECUTION REQUIRES THREE CATEGORIES"
41 PRINT ""
50 PRINT" OF INPUT: 1) A SET OF ALTERNATIVES"
51 PRINT"
60 PRINT" 2) INFORMATION REGARDING THE PERFORMANCE OF"
70 PRINT"
71 PRINT"
80 PRINT" 3) ASSOCIATED PREFERENCE INFORMATION FOR THE"
90 PRINT"
100 PRINT"
110 PRINT"
120 PRINT" OUTPUT FOR THE MODEL IS IN TERMS OF CALCULATED NUMERICAL-"
121 PRINT
130 PRINT" WORTHs THAT DESIGNATE THE FINAL SELECTION ALTERNATIVE BASED "
131 PRINT
140 PRINT" ON THE DECISION MAKER'S PREFERENCES."
141 FOR N = 1 TO 800: NEXT N
142 BEEP:INPUT " PRESS (RETURN) FOR NEXT SCREEN ""S""
143 IF "S"="S" THEN 144
144 PRINT:CLS:PRINT:PRINT
150 DIM P(20),WT(20), AV(10,20), R(2), WIC(2),SC(20)
160 PRINT" BEGIN EXECUTION BY ENTERING THE PARAMETERS IN THEIR PERCEIVED "
161 PRINT"
162 PRINT" ORDER OF IMPORTANCE, i.e. LET PARAMETER 1, P(1), REPRESENT THE "
163 PRINT"
164 PRINT" MOST VALUED, P(2) THE NEXT MOST VALUED AND P(n) THE LEAST MOST "
165 PRINT
166 PRINT" VALUED.
167 PRINT:PRINT:PRINT
168 FOR N=1 TO 1600: NEXT N
169 PRINT
170 INPUT " HOW MANY PARAMETERS WILL BE EVALUATED ";PARAMETERS
180 LET P = PARAMETERS
181 PRINT:PRINT
182 IF P > 20 THEN 183 ELSE 190
183 PRINT:PRINT " THE MAXIMUM NUMBER OF PARAMETERS THAT CAN BE ";PRINT
184 PRINT " EVALUATED IS 20. PLEASE START OVER.";PRINT:PRINT
185 GOTO 160
190 PRINT " THE SPECIFIED NUMBER OF PARAMETERS = ";
200 PRINT P
201 PRINT:PRINT:PRINT
210 LET COUNT = 0
220 INPUT " THE 1ST PARAMETER IS ":P$(1)
221 INPUT " ENTER SCALING:POS=P,NEG=N ";SC1
222 IF SC1$=""N" THEN SC(1)=-1 ELSE SC(1)=1
230 PRINT
240 GOSUB 1000
250 INPUT " THE 2ND PARAMETER IS ":P$(2)
251 INPUT " ENTER SCALING:POS=P,NEG=N ";SC2
252 IF SC2$=""N" THEN SC(2)=-1 ELSE SC(2)=1
260 PRINT
270 GOSUB 1000
280 INPUT " THE 3RD PARAMETER IS ":P$(3)
281 INPUT " ENTER SCALING:POS=P,NEG=N ";SC3
282 IF SC3$=""N" THEN SC(3)=-1 ELSE SC(3)=1

REM SCALE CHECK
PRINT SC(1), SC(2), SC(3), SC(4)
GOSUB 1000
REM GOSUB 1100
INPUT "THE 5TH PARAMETER IS "; FS(5)
INPUT " "; SC5="N" THEN SC(5)=-1 ELSE SC(5)=1
PRINT
GOSUB 1000
REM GOSUB 1100
INPUT "THE 6TH PARAMETER IS "; FS(6)
INPUT " "; SC6="N" THEN SC(6)=-1 ELSE SC(6)=1
LET COUNT=5
PRINT
GOSUB 1000
INPUT "THE 7TH PARAMETER IS "; FS(7)
INPUT " "; SC7="N" THEN SC(7)=-1 ELSE SC(7)=1
PRINT
GOSUB 1000
INPUT "THE 8TH PARAMETER IS "; FS(8)
INPUT " "; SC8="N" THEN SC(8)=-1 ELSE SC(8)=1
PRINT
GOSUB 1000
INPUT "THE 9TH PARAMETER IS "; FS(9)
INPUT " "; SC9="N" THEN SC(9)=-1 ELSE SC(9)=1
LET COUNT=10
PRINT
GOSUB 1000
INPUT "THE 10TH PARAMETER IS "; FS(10)
INPUT " "; SC10="N" THEN SC(10)=-1 ELSE SC(10)=1
PRINT
GOSUB 1000
INPUT "THE 11TH PARAMETER IS "; FS(11)
INPUT " "; SC11="N" THEN SC(11)=-1 ELSE SC(11)=1
LET COUNT=10
PRINT
GOSUB 1000
INPUT "THE 12TH PARAMETER IS "; FS(12)
INPUT " "; SC12="N" THEN SC(12)=-1 ELSE SC(12)=1
PRINT
GOSUB 1000
INPUT "THE 13TH PARAMETER IS "; FS(13)
INPUT " "; SC13="N" THEN SC(13)=-1 ELSE SC(13)=1
PRINT
GOSUB 1000
INPUT "THE 14TH PARAMETER IS "; FS(14)
INPUT " "; SC14="N" THEN SC(14)=-1 ELSE SC(14)=1
PRINT
GOSUB 1000
INPUT "THE 15TH PARAMETER IS "; FS(15)
INPUT " "; SC15="N" THEN SC(15)=-1 ELSE SC(15)=1
PRINT
GOSUB 1000
175

670 INPUT "THE 16TH PARAMETER IS ";'P$(16)
671 INPUT " ENTER SCALING:POS=P,NEG=N ";'SC16$'
672 IF SC16$="N" THEN SC(16)=-1 ELSE SC(16)=1
673 LET COUNT = 15
674 PRINT
675 GOSUB 1000
676 INPUT "THE 17TH PARAMETER IS ";'P$(17)
677 INPUT " ENTER SCALING:POS=P,NEG=N ";'SC17$
678 IF SC17$="N" THEN SC(17)=-1 ELSE SC(17)=1
679 PRINT
680 GOSUB 1000
681 INPUT "THE 18TH PARAMETER IS ";'P$(18)
682 INPUT " ENTER SCALING:POS=P,NEG=N ";'SC18$
683 IF SC18$="N" THEN SC(18)=-1 ELSE SC(18)=1
684 PRINT
685 GOSUB 1000
686 INPUT "THE 19TH PARAMETER IS ";'P$(19)
687 INPUT " ENTER SCALING:POS=P,NEG=N ";'SC19$
688 IF SC19$="N" THEN SC(19)=-1 ELSE SC(19)=1
689 PRINT
690 GOSUB 1000
691 INPUT "THE 20TH PARAMETER IS ";'P$(20)
692 PRINT
693 GOSUB 1000
694 INPUT " ENTER ";'SC20$
695 IF SC20$="N" THEN SC(20)=-1 ELSE SC(20)=1
696 LET COUNT = COUNT + 1
697 IF COUNT = P THEN 1050
698 PRINT
699 PRINT
700 RETURN
701 PRINT:PRINT
702 IF COUNT = P THEN 1100
703 INPUT " DO YOU WISH TO MAKE CHANGES IN YOUR SPECIFICATIONS ";'R$
704 PRINT
705 FOR N = 1 TO 800
706 NEXT N
707 IF R$ = "YES" THEN 2020
708 IF R$ = "NO" THEN 2060
709 PRINT:PRINT
710 IF COUNT <= 5 THEN 169
711 IF COUNT > 5 AND COUNT <= 10, GOTO 370
712 IF COUNT > 10 AND COUNT <= 15, GOTO 510
713 IF COUNT > 15 AND COUNT <= 20, GOTO 670
714 GOTO 2090
715 CLS:PRINT:PRINT
716 BEEP:PRINT " EXECUTION OF RELATIVE WEIGHT ASSIGNMENTS"
717 PRINT
718 PRINT " -------------------------------"
719 PRINT " THIS PORTION OF THE PROGRAM WILL ASSIGN RELATIVE WEIGHTS"
720 PRINT " TO THE PARAMETERS SPECIFIED ABOVE. THE MOST IMPORTANT"
721 PRINT " PARAMETER WILL BE ASSIGNED A VALUE OF 1.0. THE WEIGHT OF"
722 PRINT " EACH SUBSEQUENT PARAMETER MUST BE LESS THAN OR EQUAL TO 1.0"
723 PRINT " AND MUST BE LESS THAN OR EQUAL TO THE WEIGHT OF THE"
724 PRINT " PARAMETER IMMEDIATELY PRECEDING IT."
725 PRINT:PRINT
726 INPUT " PRESS (RETURN) FOR NEXT SCREEN ";'BMW$:IF BMW$="C" THEN 3052
727 PRINT:PRINT:PRINT " BEGIN EXECUTION "
728 FOR N = 1 TO 1500
729 NEXT N
730 PRINT
731
3000 LET W = P
3010 LET B = 1
3020 LET WTC = 0
3030 CLS:PRINT:PRINT
4000 PRINT " IF ";P$(1);" IS ASSIGNED A WEIGHT OF 1.0, specify in
4001 PRINT
4002 PRINT " DECENDING ORDER THE WEIGHT OF THE REMAINING ";W-1;" PARAMETERS.
4003 PRINT
4004 LET WT(1) = 1!
4010 FOR X = 2 TO P
4020 GOSUB 7999
4030 IF WT(X) = 1! THEN 4040 ELSE 6000
4040 PRINT:PRINT
7000 PRINT " WHAT IS THE WEIGHT FOR ";P$(X);
7001 INPUT WT(X);PRINT:PRINT
7002 LET B=B+1
7003 LET WTC = WT(X)
7004 IF WT(X) = 1! AND WTC < 7090 ELSE 7010
7010 LET WT(1) = 1; LET BACK = WT(X) - WT(X-1)
7040 PRINT " THE SPECIFIED WEIGHT IS TOO HIGH. YOUR LAST ASSIGNMENT 
7041 PRINT
7050 PRINT " EXCEEDS THE WEIGHT CONDITION BY ";ABS(BACK)
7070 PRINT:PRINT:PRINT " PLEASE REASSIGN INDIVIDUAL WEIGHS.";PRINT:PRINT:PRINT
7071 FOR H = 1 TO 3400:NEXT H:BEEP
7080 LET BACK = 0:GOTO 3080
7090 IF B = P THEN 7999 ELSE 7998
7998 RETURN
7999 PRINT:CLS:PRINT:PRINT
8000 PRINT TAB(8); "RANK"; TAB(20); "PARAMETER"; TAB(44); "WEIGHT
8001 PRINT " ------------------------------------------
8002 PRINT
8010 FOR I = 1 TO P
8020 PRINT TAB(8); I; TAB(20); P$(I); TAB(44); WT(I):PRINT
8030 NEXT I
9000 REM STEP 9 - NORMALIZATION OF RELATIVE WEIGHTS
9001 PRINT " ANSWER YES OR NO TO THE FOLLOWING QUESTION ";PRINT
9002 PRINT " DO YOU WISH TO MAKE CHANGES IN THE WEIGHT ASSIGNMENTS ";W$
9003 IF W$ = "YES" THEN 9005 ELSE 9009
9005 LET BACK=0:GOTO 3071
9009 LET CHECK = 0
9010 FOR J = 1 TO P
9020 LET DENOM = WT(J) + DENOM
9030 NEXT J
9040 DIM NWT(20)
9050 FOR K = 1 TO P
9060 LET NWT(K) = WT(K) / DENOM
9070 NEXT K
9080 REM NORMALIZATION CHECK
9081 FOR L = 1 TO P
9082 LET CHECK = NWT(L) + CHECK
9083 NEXT L
9084 PRINT
9085 PRINT
9086 REM PRINT " CHECK = "; CHECK
9087 PRINT
10000 DIM ALT$(10),SCORE(10)
10001 REM STEP 10 - SCORE THE ALTERNATIVES USING THE ADDITIVE MODEL.
10002 PRINT:LET PP = 0:CLS:PRINT:PRINT
10010 BEEP:PRINT " EXECUTION OF ALTERNATIVE SPECIFICATIONS ";PRINT
10011 PRINT " ------------------------------------------
10020 PRINT:PRINT " ENTER THE NUMBER OF ALTERNATIVES TO BE EVALUATED ";
10030 INPUT NALT
10040 FOR R = 1 TO NALT
10041 PRINT
10042 PRINT
10050 PRINT " WHAT IS ALTERNATIVE NUMBER ":R: " ";
10051 INPUT ALT(R)
10052 PRINT " ENTER THE APPROPRIATE VALUE CORRESPONDING TO THE PARAMETER 
10056 PRINT
10057 PRINT " SHOWN BELOW FOR THE ";ALT(R);" ALTERNATIVE."
10058 PRINT
10070 FOR S = 1 TO P
10071 PRINT":"P(S) ";
10080 INPUT AVP(S)
10082 NEXT S
10083 IF PP > 0 THEN 10097 ELSE 10084
10084 PRINT: INPUT" PRESS (RETURN) FOR NEXT ALTERNATIVE "; ZZ$: PRINT
10085 IF ZZ$="YES" THEN 10086 ELSE 10101
10086 CHRS(12)
10087 PRINT " ENTER THE NUMBER YOU WISH TO CHANGE "; T
10090 LET PP = T:LET R = T:GOTO 10041
10097 INPUT" ARE MORE CHANGE S REQUIRED "; BB$: PRINT
10098 IF BB$="YES" THEN 10090 ELSE 10101
10100 REM SCORE MODEL WITH ANCHORED DENOMINATOR
10101 DIM SWT(20):SC=O
10102 LET SS = 1
10103 LET TT = 1
10105 FOR RR = 1 TO NALT
10107 IF AV(RR,SS) > SWT(TT) THEN 10108 ELSE 10117
10108 LET SWT(TT) = AV(RR,SS)
10109 NEXT RR
10110 LET SS = SS + 1
10111 LET TT = TT + 1
10112 IF SS > P THEN 10117
10113 GOTO 10105
10117 FOR T = 1 TO NALT
10118 FOR Q = 1 TO P
10119 REM PRINT NWT(Q), AV(T,Q), SWT(T)
10120 SCORE(T) = (SC(Q) * NWT(Q)) + (AV(T,Q)/SWT(Q))
10121 LET SC = SCORE(T) + SC
10122 NEXT Q
10123 NEXT T
10125 PRINT
10126 LET SEL = -10000
10127 FOR MM = 1 TO NALT
10128 IF SCORE(MM) > SEL THEN 10138 ELSE 10170
10129 LET SEL = SCORE(MM):LET AN = MM
10130 NEXT MM
10136 FOR MM = 1 TO NALT
10139 PRINT " ****************** INPUT SUMMARY ******************
10143 PRINT:CLS:COLOR 1,1,0:PRINT:PRINT
10144 PRINT" " ALTS. EVALUATED ":TAB(20);"PAR A METERS ":TAB(44); "VALUES";
10147 PRINT TAB(52);"WEIGHTS ":TAB(61);"SCALING"
10148 PRINT" "---
10149 PRINT
10150 FOR X=1 TO NALT
10152 FOR Y=1 TO P
10154 PRINT TAB(20):P(S)TAB(44)AV(X,Y):TAB(52):WT(X):TAB(64):SC(X,Y)
10156 PRINT:INPUT":PRESS (RETURN) FOR NEXT SUMMARY "; ZZ$:PRINT:PRINT
10158 NEXT X
10207 PRINT: BEEP
10210 PRINT" ******************** EVALUATION SUMMARY **************************
10213 PRINT"-------------------------------------------------------------------------------------
10216 PRINT TAB(8);"ALTERNATIVE SCORES"
10219 PRINT"-------------------------------------------------------------------------------------
10222 FOR U=1 TO NALT
10225 PRINT:PRINT TAB(4);ALT$(U);" = " SCORE(U)
10228 LPRINT:NEXT U
10229 PRINT TAB(8); "FINAL SELECTION ALTERNATIVE "
10230 PRINT"-------------------------------------------------------------------------------------
10231 BEEP:PRINT"  SELECT : " ALT$(NN)
10233 PRINT
10234 PRINT"-------------------------------------------------------------------------------------
10235 PRINT"-------------------------------------------------------------------------------------
10300 END
0k
A.3.1 Listing of Decision Model Output.

MATERIAL MANAGEMENT DECISION SUPPORT MODEL

PROGRAM DESIGNER: DARRELL A. DAVIS
IEOR DEPT. V P I & S U

THIS PROGRAM IS DESIGNED TO EVALUATE ALTERNATIVE MATERIAL DISTRIBUTION METHODS. EXECUTION REQUIRES THREE CATEGORIES OF INPUT:

1) A SET OF ALTERNATIVES

2) INFORMATION REGARDING THE PERFORMANCE OF THE ALTERNATIVES.

3) ASSOCIATED PREFERENCE INFORMATION FOR THE ALTERNATIVES.

OUTPUT FOR THE MODEL IS IN TERMS OF CALCULATED NUMERICAL WORTHS THAT DESIGNATE THE FINAL SELECTION ALTERNATIVE BASED ON THE DECISION MAKER'S PREFERENCES.

PRESS (RETURN) FOR NEXT SCREEN?

BEGIN EXECUTION BY ENTERING THE PARAMETERS IN THEIR PERCEIVED ORDER OF IMPORTANCE, i.e. LET PARAMETER 1, P(1), REPRESENT THE MOST VALUED, P(2) THE NEXT MOST VALUED AND P(n) THE LEAST MOST VALUED.

HOW MANY PARAMETERS WILL BE EVALUATED? 6

THE SPECIFIED NUMBER OF PARAMETERS = 6

THE 1ST PARAMETER IS ? COST ENTER SCALING: POS=P, NEG=N ? N

THE 2ND PARAMETER IS ? BACKORDER TSYS ENTER SCALING: POS=P, NEG=N ? N

THE 3RD PARAMETER IS ? UPS TO BMN ENTER SCALING: POS=P, NEG=N ? N

THE 4TH PARAMETER IS ? BULK TO RACK ENTER SCALING: POS=P, NEG=N ? N

THE 5TH PARAMETER IS ? AVERAGE ISSUE TIME ENTER SCALING: POS=P, NEG=N ? N

ANSWER YES OR NO TO THE FOLLOWING QUESTION

DO YOU WISH TO MAKE CHANGES IN YOUR SPECIFICATIONS? NO

EXECUTION OF RELATIVE WEIGHT ASSIGNMENTS

-----------------------------
THIS PORTION OF THE PROGRAM WILL ASSIGN RELATIVE WEIGHTS
TO THE PARAMETERS SPECIFIED ABOVE. THE MOST IMPORTANT
PARAMETER WILL BE ASSIGNED A VALUE OF 1.0. THE WEIGHT OF
EACH SUBSEQUENT PARAMETER MUST BE LESS THAN OR EQUAL TO 1.0
AND MUST BE LESS THAN OR EQUAL TO THE WEIGHT OF THE
PARAMETER IMMEDIATELY PRECEDING IT.

PRESS "RETURN" FOR NEXT SCREEN?

BEGIN EXECUTION

IF COST IS ASSIGNED A WEIGHT OF 1.0, SPECIFY IN
DECENDING ORDER THE WEIGHT OF THE REMAINING 5 PARAMETERS.
WHAT IS THE WEIGHT FOR BACKORDER TSYS? .75
WHAT IS THE WEIGHT FOR UPS TO BIN? .6
WHAT IS THE WEIGHT FOR BULK TO RACK? .5
WHAT IS THE WEIGHT FOR AVERAGE ISSUE TIME? .3
WHAT IS THE WEIGHT FOR SYSTEM FLEXIBILITY? .235

<table>
<thead>
<tr>
<th>RANK</th>
<th>PARAMETER</th>
<th>WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>COST</td>
<td>1</td>
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<tr>
<td>0</td>
<td>BACKORDER TSYS</td>
<td>.75</td>
</tr>
<tr>
<td>0</td>
<td>UPS TO BIN</td>
<td>.6</td>
</tr>
<tr>
<td>0</td>
<td>BULK TO RACK</td>
<td>.5</td>
</tr>
<tr>
<td>0</td>
<td>AVERAGE ISSUE TIME</td>
<td>.3</td>
</tr>
</tbody>
</table>
SYSTEM FLEXIBILITY

ANSWER YES OR NO TO THE FOLLOWING QUESTION
DO YOU WISH TO MAKE CHANGES IN THE WEIGHT ASSIGNMENTS? NO

EXECUTION OF ALTERNATIVE SPECIFICATIONS

ENTER THE NUMBER OF ALTERNATIVES TO BE EVALUATED? 6

WHAT IS ALTERNATIVE NUMBER 1? BASE(2/3)WS/JIS

ENTER THE APPROPRIATE VALUE CORRESPONDING TO THE PARAMETER SHOWN BELOW FOR THE BASE(3WS/JIS) ALTERNATIVE.

COST = ? 0
BACKORDER TSYS = ? 24.47
UPS TO BIN = ? 23.36
BULK TO RACK = ? 84.94
AVERAGE ISSUE TIME = ? 26.5
SYSTEM FLEXIBILITY = ? 5

PRESS (RETURN) FOR NEXT ALTERNATIVE?

WHAT IS ALTERNATIVE NUMBER 2? BASE(2WS/4IS)

ENTER THE APPROPRIATE VALUE CORRESPONDING TO THE PARAMETER SHOWN BELOW FOR THE BASE(2WS/4IS) ALTERNATIVE.

COST = ? 0
BACKORDER TSYS = ? 11.39
UPS TO BIN = ? 23.36
BULK TO RACK = ? 3.28
AVERAGE ISSUE TIME = ? 12.26
SYSTEM FLEXIBILITY = ? 5

PRESS (RETURN) FOR NEXT ALTERNATIVE?

WHAT IS ALTERNATIVE NUMBER 3? BARCODE SCANNING SYS444 SYSTEM

ENTER THE APPROPRIATE VALUE CORRESPONDING TO THE PARAMETER SHOWN BELOW FOR THE BARCODE SYSTEM ALTERNATIVE.

COST = ? 25000
BACKORDER TSYS = ? 11.59
UPS TO BIN = ? 7.14
BULK TO RACK = ? 3.28
AVERAGE ISSUE TIME = ? 12.26
SYSTEM FLEXIBILITY = ? 7

PRESS (RETURN) FOR NEXT ALTERNATIVE?
WHAT IS ALTERNATIVE NUMBER 4? BAR/CART SYSTEM

ENTER THE APPROPRIATE VALUE CORRESPONDING TO THE PARAMETER SHOWN BELOW FOR THE BAR/CART SYSTEM ALTERNATIVE.

COST = ? 50000
BACKORDER TSYS = ? 12.32
UPS TO BIN = ? 6.3
BULK TO RACK = ? 3.852
AVERAGE ISSUE TIME = ? 12.408
SYSTEM FLEXIBILITY = ? 7.5

PRESS (RETURN) FOR NEXT ALTERNATIVE?

WHAT IS ALTERNATIVE NUMBER 5? CAROUSEL SYSTEM

ENTER THE APPROPRIATE VALUE CORRESPONDING TO THE PARAMETER SHOWN BELOW FOR THE CAROUSEL SYSTEM ALTERNATIVE.

COST = ? 375000
BACKORDER TSYS = ? 3.2878
UPS TO BIN = ? 11.88
BULK TO RACK = ? 33.85
AVERAGE ISSUE TIME = ? .308
SYSTEM FLEXIBILITY = ? 5

PRESS (RETURN) FOR NEXT ALTERNATIVE?

WHAT IS ALTERNATIVE NUMBER 6? ASRS

ENTER THE APPROPRIATE VALUE CORRESPONDING TO THE PARAMETER SHOWN BELOW FOR THE ASRS ALTERNATIVE.

COST = ? 882000
BACKORDER TSYS = ? 1.961
UPS TO BIN = ? 11.87
BULK TO RACK = ? 33.85
AVERAGE ISSUE TIME = ? 22.96
SYSTEM FLEXIBILITY = ? 8

PRESS (RETURN) FOR NEXT ALTERNATIVE?

ANSWER YES OR NO TO THE FOLLOWING QUESTION
DO YOU WISH TO RESPECIFY ALTERNATIVES OR PARAMETER VALUES? NO

***************************************************************************** INPUT SUMMARY *****************************************************************************

ALTS. EVALUATED PARAMETERS VALUES WEIGHTS SCALING
-----------------------------------------------
BASE(JWS/JJS) COST 0 1 -1
BASE(JWS/JJS) BACKORDER TSYS 24.47 .75 -1
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<tr>
<th>BASE (3WS/3IS)</th>
<th>UPS TO BIN</th>
<th>23.36</th>
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<th>-1</th>
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<tr>
<td>BASE (3WS/3IS)</td>
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<td>-1</td>
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<tr>
<td>BASE (3WS/3IS)</td>
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<td>.3</td>
<td>-1</td>
</tr>
<tr>
<td>BASE (3WS/3IS)</td>
<td>SYSTEM FLEXIBILITY</td>
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<td>.25</td>
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PRESS (RETURN) FOR NEXT SUMMARY ?

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<tr>
<th>BASE (2WS/4IS)</th>
<th>COST</th>
<th>0</th>
<th>1</th>
<th>-1</th>
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</thead>
<tbody>
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<td>BASE (2WS/4IS)</td>
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<td>BASE (2WS/4IS)</td>
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<td>.6</td>
<td>-1</td>
</tr>
<tr>
<td>BASE (2WS/4IS)</td>
<td>BULK TO RACK</td>
<td>3.28</td>
<td>.5</td>
<td>-1</td>
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<tr>
<td>BASE (2WS/4IS)</td>
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<tr>
<td>BASE (2WS/4IS)</td>
<td>SYSTEM FLEXIBILITY</td>
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<td>.25</td>
<td>1</td>
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PRESS (RETURN) FOR NEXT SUMMARY ?

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<th>BAR/CART SYSTEM</th>
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<th>-1</th>
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</thead>
<tbody>
<tr>
<td>BAR/CART SYSTEM</td>
<td>BACKORDER TSYS</td>
<td>12.32</td>
<td>.75</td>
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</tr>
<tr>
<td>BAR/CART SYSTEM</td>
<td>UPS TO BIN</td>
<td>6.3</td>
<td>.6</td>
<td>-1</td>
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<tr>
<td>BAR/CART SYSTEM</td>
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<tr>
<td>BAR/CART SYSTEM</td>
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<tr>
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PRESS (RETURN) FOR NEXT SUMMARY ?

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<tr>
<th>CAROUSEL SYSTEM</th>
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<td>CAROUSEL SYSTEM</td>
<td>AVERAGE ISSUE TIME</td>
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CAROUSEL SYSTEM  SYSTEM FLEXIBILITY  5  .25  1
PRESS (RETURN) FOR NEXT SUMMARY ?

ASRS  COST  882000  1  -1
ASRS  BACKORDER TSYS  .1961  .75  -1
ASRS  UPS TO BIN  11.87  .6  -1
ASRS  BULK TO RACK  33.65  .5  -1
ASRS  AVERAGE ISSUE TIME  .2296  .3  -1
ASRS  SYSTEM FLEXIBILITY  0  .25  1
PRESS (RETURN) FOR NEXT SUMMARY ?

JECT SUMMARY REP://

ALTERNATIVE SCORES

BASE (JWS/3IS) = -.5863971
BASE (JWS/4IS) = -.3914945
BARCODE SYSTEM = -.1489165
BAR/CART SYSTEM = -.1543757
CAROUSEL SYSTEM = -.2310657
ASRS = -.3713965

FINAL SELECTION ALTERNATIVE

SELECT : BARCODE SYSTEM

Ok
The vita has been removed from the scanned document