Louisiana State University

LSU Digital Commons

1988

Development of a Computer-Integrated Manufacturing Simulation Model: A Hybrid Systems Approach.

Vinay Kumar Vasudev
Louisiana State University and Agricultural & Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_disstheses

Recommended Citation

INFORMATION TO USERS

Development of a computer-integrated manufacturing simulation model: A hybrid systems approach

Vasudev, Vinay Kumar, Ph.D.

The Louisiana State University and Agricultural and Mechanical Col., 1988

PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy.
Problems encountered with this document have been identified here with a check mark ___√___.

1. Glossy photographs or pages _____

2. Colored illustrations, paper or print _____

3. Photographs with dark background _____

4. Illustrations are poor copy _____

5. Pages with black marks, not original copy ___✓___

6. Print shows through as there is text on both sides of page _____

7. Indistinct, broken or small print on several pages ___✓___

8. Print exceeds margin requirements _____

9. Tightly bound copy with print lost in spine _____

10. Computer printout pages with indistinct print _____

11. Page(s) _____ lacking when material received, and not available from school or author.

12. Page(s) _____ seem to be missing in numbering only as text follows.

13. Two pages numbered _____. Text follows.

14. Curling and wrinkled pages _____

15. Dissertation contains pages with print at a slant, filmed as received ___✓___

16. Other_____

_____

_____

U·M·I

Development of a Computer-Integrated Manufacturing
Simulation Model: A Hybrid Systems Approach

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

Interdepartmental Programs in Engineering

by

Vinay Kumar Vasudev
B.S., Ranchi University, 1974
M.S., Louisiana State University, 1983
May, 1988

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The key to the successful "factory of the future" will be the effective coordination of managerial functions and production operations. The research presented in this dissertation addresses this "coordination" issue, especially in terms of understanding the impact and possibilities which exist in an information-rich environment. Such an environment is often referred to in the literature as being a computer-integrated manufacturing (CIM) environment. An interactive simulation modeling program, MOSES (Manufacturing Organization Simulation and Evaluation System), was developed for the purpose of describing, analyzing, and understanding such manufacturing systems.

MOSES is a copyrighted computer program, a menu-driven, interactive, simulation modeling tool. MOSES users are able to define the manufacturing environment to be simulated by keying in data values (e.g., products, bills of material, and production rates) which describe the organization. MOSES then uses these data values to "build the manufacturing simulation model." That is, once the manufacturing parameters have been defined, MOSES can simulate the manufacturing organization (from orders through distribution) without the user having to write any computer code or having

to understand the principles of simulation modeling. MOSES users are then able to interact with the manufacturing organization as "managers" in the dynamic simulation environment. This interactive capability allows MOSES users to test various manufacturing scenarios, watch the model's progress from the perspectives of different organizational functions (e.g., from marketing or from production), override model-generated decisions (e.g., by changing the demand forecast), and view the results.

The MOSES approach to simulation modeling differs from traditional approaches. In short, MOSES uses both mathematical and logical modeling principles, employs traditional simulation modeling techniques but in combination with database technology, and includes the user as an integral component in the simulation process.

Chapter I

INTRODUCTION

The key to the successful "factory of the future" will be the effective coordination of managerial functions and production operations. To accomplish this, it will be necessary to develop management tools which provide insight and understanding of the complex interrelationships inherent in the manufacturing organization. The effective application of this concept on a widespread basis throughout modern industry will depend on an understanding of the impact and possibilities of this type of arrangement.

A great deal of effort is currently being expended to integrate computer-aided design and computer-aided manufacturing techniques into the workplace. Both the potential and the obstacles related to this implementation process are tremendous. Before such concepts can become commonplace, however, a clear understanding of the complex data and material interactions which must take place in such an environment is required.

1.1 STATE OF THE "FACTORY OF THE FUTURE"

While remarkable amounts of progress have been made in specific areas of the CAD/CAM environment (e.g., computer

graphics, computer-aided production planning and control, robotics, and computer numerically controlled machines), it is only in a few isolated situations that these and other similar concepts have been implemented into anything even resembling an integrated, organizational whole. Numerous applications of computerized automation have been implemented in production facilities around the nation. However, most of these facilities have been automated through the integration of a few pieces of programmable equipment, sometimes referred to as "islands of automation," into the manufacturing process. While these "islands of automation" certainly represent the beginning of the "factory of the future," their implementation in no way indicates that the other pieces of the puzzle are ready for placement.

1.2   ISSUES IN ACHIEVING THE "FACTORY OF THE FUTURE"

It is sometimes implied that the reason we do not yet have true computer-integrated manufacturing (CIM) is that we somehow lack the full contingent of software and hardware to make CIM possible. In some ways that is true, since not everything can be connected to everything else. But scientists, scholars and engineers are working diligently to perfect the necessary software and hardware and to establish the protocols that will allow the various factory floor components to talk to one another. Thus, the required technology is either here or will be available in the near

future.

Then what is missing in making CIM a reality? What is keeping us from implementing the idea of CIM? The answer lies in the fact that the technology is not the key issue. The key issue is our view of the "factory of the future." We think about the brick-mortar factories of today and of transplanting them into the future by using the newly developed technologies. Our vision of the factory of the future is the factory of today with more gadgetry, with the same functions being performed at faster speeds and with higher efficiency resulting from the increased automation. Because this "new" system is much more than better hardware and software, this view is inappropriate. What we should be thinking about are ways to solve manufacturing-related problems, ways to organize and define the new roles of the major functional groups within the organization, and of better ways to manage a dynamic factory within a dynamic environment. In short, the major challenge in implementing the "factory of the future" is management, not technology [1,2,3]. Problem solving, organizing, and managing are not technology issues.

Regarding the "factory of the future," Tompkins and White [4] have said : "In many situations, the missing ingredients are not hardware components; rather, what is lacking is an economic environment (a combination of value, volume, and variety) making it cost effective to automate all factory

operations." Our contention is that the issue is more complicated than "simply" one of economics; that having the monetary incentive and necessary resources serves only to move the central issue - the matter of new and uncertain interrelationships - one step closer to reality. In fact, we believe that many of the interrelationship issues should and can be addressed in advance. Further, by addressing and understanding these interrelationships in advance, we can more rationally choose the ways we implement and use the new technologies. That is, before we can have widespread, successful implementations of "factories of the future," there must be understanding of the impact of computer-integrated manufacturing as a part of the organizational whole, as well as understanding of the interactions between its subsystems.

This is not meant to imply that economic consequences are not important. Successful manufacturing organizations must maintain a competitive edge in the market place. The market is the place where an organization survives or dies and, obviously, no manufacturing organization can thrive while ignoring the realities of the market place. Customers have certain expectations of product quality, cost, and availability. What rudimentary or sophisticated manufacturing systems are at work behind the scenes to provide products which meet those expectations is not a customer concern. Thus, it is mandatory for all implementations of "factories of the future" to constantly keep the realities of the

market place in perspective such that organizational plans for automation are evaluated continuously within the context of their business environment.

As such, there is an impending need to study the basic nature of manufacturing (i.e., the "science" of manufacturing) within its natural environment – the organization – and to identify its functions and their interrelationships. There is a need to devise a framework that enables us to understand how to reconfigure the various components of the manufacturing process (design, production, distribution, management) to most efficiently and effectively integrate the computing resources available [5]. This includes developing computer-based models to simulate the manufacturing environment and the accompanying information flow. Such models may then be used as testing grounds, as management laboratories, for experimentation, analysis and, ultimately, understanding. Understanding, as it is used here, implies the manufacturing organization as a whole. Only through this type of controlled modeling environment will managers of manufacturing be able to understand larger pieces of the manufacturing organization puzzle and, eventually, be better able to manage the manufacturing-related functions.

1.3 MANUFACTURING ORGANIZATION SIMULATION AND EVALUATION SYSTEM (MOSES)

In order to address some of the concerns surrounding the

"factory of the future," a computer simulation model named MOSES (Manufacturing Organization Simulation and Evaluation System) has been developed. There are three potential uses of the model: in instruction, in research, and for decision-making in actual manufacturing environments. The instructional and research aspects of the model will take place through the inclusion of MOSES users as "managers" in the simulated manufacturing environment. Each manager will interact with the model by assuming responsibility for a function (such as marketing, inventory, or production) and will be provided with specific operational goals consistent with that function. The manager will then sit at a microcomputer and use a series of screens which allow him to interact with - and to some degree control - the manufacturing environment as a decision-maker. He will also be able to track the results of his actions through a series of interim reports - all from the perspective and inherent limitations of that function.

MOSES has obvious application as an instructional tool - both for students and for professionals. For example, suppose the MOSES user first takes the perspective of a production planner. He could examine sales forecasts, current resource levels, and the organization's short-term and long-term objectives before setting up a production plan. Then, as time passes and events occur in the simulated environment, the manager could view the impact of his plan on other

parts of the organization. How has inventory been affected? What affect has the plan had on the company's cash flow situation? How has the marketing function been affected? By serving at different times as the manager of various functions throughout the manufacturing organization, the MOSES user has the opportunity to gain experience and understanding – from several key perspectives – in different parts of a realistic computer-integrated manufacturing organization. The long-term benefit of these multi-functional views is invariably a clearer understanding of each function's place in the organization as a whole. (Note: Management training programs in large companies have for years assigned trainees to spend time in each of several parts of their organization in order for the trainees to better understand each function.)

MOSES is an unprecedented research tool. Turner, et al. [6] have said "A professor of industrial and systems engineering cannot bring a production system into a laboratory. It is too big, too complex. Furthermore, it involves human beings who are not only unpredictable and difficult to measure, but who would also be unwilling to be part of a laboratory experiment." MOSES allows both the complexity issue and, to a significant degree, the people issue to be addressed in a laboratory environment. For example, if an organization completely loses all orders it cannot fill immediately (i.e., no backorders), what is the affect on the

organization? Or, suppose that the manufacturing organization is considering implementing a Just-In-Time inventory policy. How much of each type of inventory should the organization keep on hand? Or, what are the organizational effects of long-term overtime production? Without a tool such as MOSES, issues like these can only be answered subjectively.

The same model is applicable to an actual production organization. Managers typically view success or failure from sub-optimal, local perspectives (i.e., how "my" part of the organization is fairing). In terms of the overall organization, these managers are often placed in contention with one another – responsible only for their piece of the puzzle. A super-manager (i.e., section chief or department head), who often has only partial understanding of the individual process components, is responsible for arbitrating among them (i.e., managing) – "for the good of the organization." The theory is that this local-view contentious approach to management leads to optimal or near-optimal organizational results.

The problem with the contentious approach described above is that its structure is by design the opposite of teamwork (even though words of that nature are often inappropriately associated with the approach). Rather than leading to openness and cooperation between organizational subunits (typical characteristics of a team environment), it more likely

leads to secrecy, self-serving decisions, and antagonism.

The value of a "total view," organizational-success-oriented model in such an environment may now be apparent. Actual managers would have the opportunity to view the results of their potential decisions on parts of the organization other than their own. For example, the manager of production planning could see the impact of certain decisions he might make from the varied perspectives of the managers of inventory, sales, distribution, and finance, forcing (at least, potentially) the manager to abandon his localized view of organizational success.

1.4 OBJECTIVES

It is apparent that the task of developing such a comprehensive model is extremely complex and could have become unachievable (especially within the scope of this dissertation research) if some realistic limits had not been set. In order to achieve tangible and significant results during this research effort, the main objective was set for the completed research to include a computer-based manufacturing organization model composed of a realistic subset of manufacturing system components. More specifically, the research had the following objectives:

1. Study the nature of the generic manufacturing system and identify its key functions and their

interrelationships with one another.

2. Develop a computer-integrated manufacturing organization simulation model which incorporates the following unique, yet interrelated, characteristics:

    a. The model should be able to display the immediate effect of a multitude of actions and events which take place in a manufacturing environment.

    b. The model should utilize the multi-disciplinary approach by integrating concepts of numerical simulation, intelligent simulation, information systems, database management, structured analysis and other suitable techniques.

    c. The model should allow a novice, a non-expert, a manager-in-training, a student, or a seasoned manager to interact in a meaningful manner with the various functions of the computer-integrated manufacturing model and to understand the relationships between the functions of the manufacturing organization.

1.5   DISSERTATION OVERVIEW

This dissertation is divided into eight chapters. Chapter 1, INTRODUCTION, introduces the subject of the "factory of the future" and discusses the issues which are key to the implementation of the "factory of the future." MOSES is described in this chapter as a tool capable of addressing some of those issues. Finally, the objectives of this dissertation research are presented.

Chapter 2, BACKGROUND AND NEED, investigates the background and need for the dissertation research. The need for increased manufacturing productivity is established and the shift in emphasis regarding various manufacturing cost components is discussed. In this context, the meaning of CIM is presented and current implementations of CIM are explored, leading to the basis for the research presented in this dissertation. Also, prior research efforts in the same general area are discussed.

Chapter 3, HYBRID MODELING APPROACH, discusses the hybrid systems approach taken in developing MOSES. Three distinct methodologies of computer-based simulation, database management concepts and intelligent simulation are presented. The integration of computer-based simulation with database concepts is discussed, along with a discussion of the appropriateness of combining intelligent simulation with this modeling approach.

Chapter 4, MOSES: CONCEPTUAL DESIGN, presents the phil-

osophy behind the conceptual design of MOSES. The simulation structure of MOSES is discussed vis-a-vis the traditional simulation structure and concepts behind the MOSES-user interaction are presented.

Chapter 5, MOSES: FUNCTIONAL OVERVIEW, presents MOSES at the functional level. The MOSES design is discussed from the perspective of the four basic functional areas of a manufacturing organization (i.e., marketing, inventory, production, and accounting). Various subfunctions are also discussed.

Chapter 6, MOSES: PHYSICAL DESIGN, discusses the physical details of MOSES. Several important program design considerations are presented along with some of the model's unique interactive features. The criteria applied during the selection process for MOSES' hardware and software are discussed. Finally the issues of program verification and validation are addressed.

Chapter 7, MOSES: IN ACTION, includes a short MOSES simulation session. Its purpose is to provide a brief look at how users might interact with MOSES to analyze a manufacturing organization.

Finally, Chapter 8, CONCLUSIONS AND FURTHER RESEARCH, summarizes the contribution of this research effort and presents conclusions and recommendations for the future research and improvements.

Chapter II

BACKGROUND AND NEED

There is a strong push for increased productivity within the
manufacturing industry in this country. This has been accel-
erated by fierce competition in world markets. Evidence of
this national need for higher productivity is seen in the
increasing amounts of research, development, and application
being carried out with advanced technology, aided by high
productivity hardware and software [7,8]. Rapid developments
in electronics and computer systems with their unique and
powerful capabilities are serving as catalysts in this
process.

2.1 NEED FOR INCREASED MANUFACTURING PRODUCTIVITY

The country's service sector, the non-wealth-producing com-
ponent of the economy, is necessary for a high standard of
living and quality of life. In fact, the service sector
accounts for 66 percent of the United States' Gross National
Product (GNP). Nevertheless, the service sector must depend
on the wealth-producing components of the national economy,
such as manufacturing, as its base. In simple terms, not
everyone can be in the business of selling shoes; someone
must make the shoes.

The Society of Manufacturing Engineers has emphasized the continuing need to reduce the cost of creating real wealth [9]. In fact, manufacturing accounts for 68 percent of the direct, real-wealth producing activity in the United States. Hence, a decrease in the cost of wealth production would directly increase the standard of living, quality of life, level of employment and general economic well-being of our nation. As such, it is important for the industrialized nations like the United States to seek out ways for reducing manufacturing costs.

In light of the above facts, it is interesting to note that manufacturing productivity data does not show a significant growth over the past 35 years. The data shown in Table 2.1 was published in 1985 by the U.S. Bureau of Labor Statistics. The statistics indicate only small improvement in United States manufacturing output between 1950 and 1983 [10]. In fact, productivity improvement has been especially

Period	Average Annual Change
1950 - 1973	4.0%
1973 - 1983	0.9%
1950 - 1983	3.1%

Table 2.1: Changes in U.S. Manufacturing Output [10].

poor during the decade between 1973 and 1983, a time of generally high inflation.

Figure 2.1 represents a breakdown of manufacturing costs as they were in the 1920's and as they are now. In the 1920's, direct labor costs, material costs, and overhead costs were all about equal. Engineering and engineering management efforts over several decades have resulted in reduced labor costs, but on a comparative scale, material costs and overhead costs have either remained the same or increased.
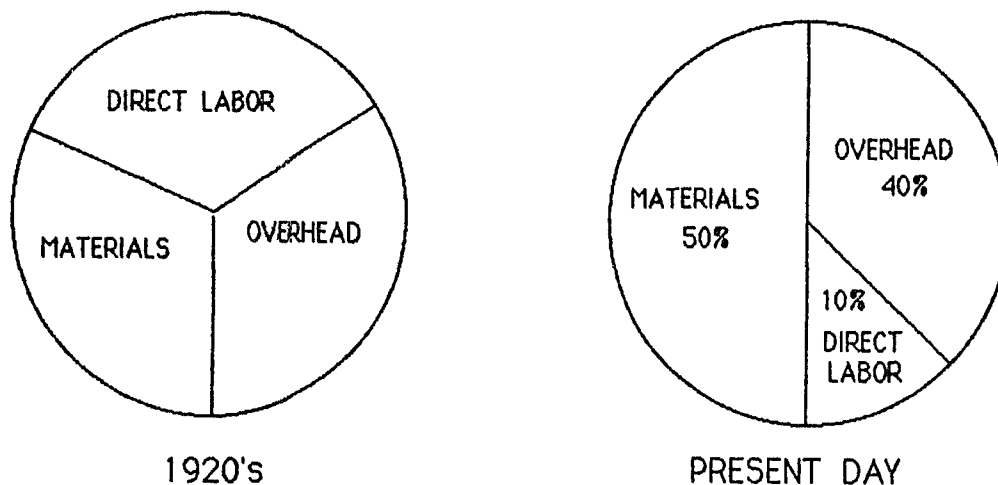
Figure 2.1: Breakdown of Manufacturing Costs

Further, the following statistics concerning batch manufacturing in the United States [1,11,12,13,14] strongly underline the need for a shift in emphasis from the traditional areas of productivity concerns, such as labor and

materials, to management and production control - and to the
communication interfaces between these subsystems.

1.   The cost of a typical manufactured product is 10%
     direct labor, 50% direct material, and 40% over-
     head (inventory storage, equipment utilization,
     and manufacturing management).

2.   Fully 30% of a work day is lost through scheduling
     problems, unclear communication of assignments,
     improper staffing and poor discipline. This is
     true throughout both labor and management ranks.

3.   About   85% of total batch manufacturing costs are
     incurred   during the manufacturing process. The
     other 15% occur during the design phase.

4.   An in-process unit of work is idle 95% of the
     time;   that is, in-process product units are
     actively worked on only 5% of the time.

5.   Of the above mentioned 5% active time, only about
     30% (or 1.5% overall) is productive time, for
     example, time spent in the actual cutting of metal
     which adds value to the product.

6.   Machines sit idle over 60% of the time because of
     equipment failure, fixturing, tool   change,
     loading/unloading, and incomplete use of second
     and third shifts, material outages, and the over
     abundance of certain types of equipment.

7. The bottom line is that "value adding operations" account for only 8% of a typical workpiece's total time in manufacturing (Figure 2.2).
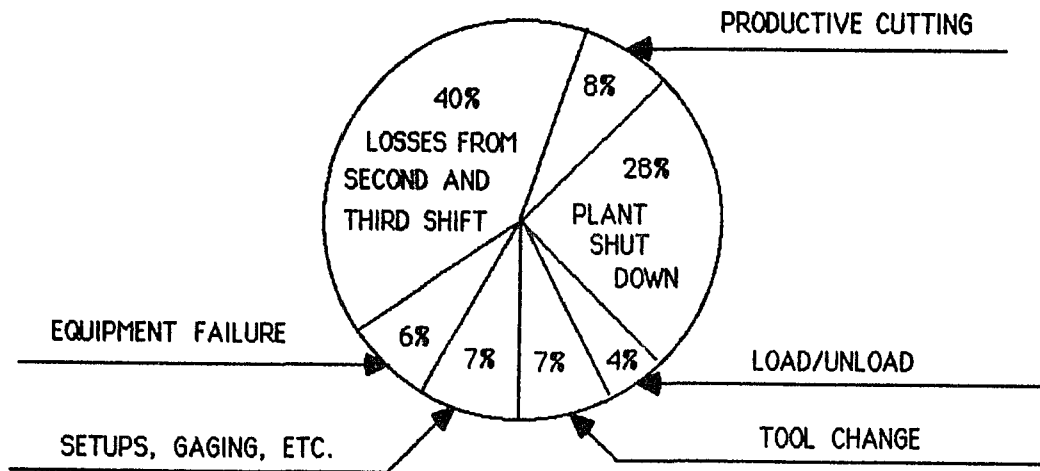
Figure 2.2: Distribution of Time Spent in Batch Manufacturing

Solutions to all the above problems are being sought through computer-integrated manufacturing (CIM) systems, which are often billed as the panacea for all manufacturing ills. In fact, the needs have become so crucial in some industries that slogans like "automate, emigrate, or evaporate" have begun to surface. Some industries are hoping to stay competitive by cutting down on their direct labor costs through the employment of "cheap foreign labor." But, as is apparent from the above list of statistics, placing too much

emphasis on labor costs is inappropriate. Ingersoll Engineers have determined that "even if we eliminate every man and woman in our direct labor force, we would only reduce from 40% to 30% the cost advantage that some overseas competitors enjoy" [15].

2.2 COMPUTER-INTEGRATED MANUFACTURING (CIM)

Computer-Integrated Manufacturing (CIM) is an over used term having a myriad of meanings to different people and in different industrial settings. In some of the recent literature, CIM is loudly proclaimed to be "the answer" to all the woes facing a manufacturing company. But it is not necessarily clear "what questions" CIM actually answers [16].

Ironically, there is no one commonly accepted definition of computer-integrated manufacturing. The term "CIM" is not defined in the first definitive book on CIM by Harrington [17], written in 1973. Although the author provides a thorough explanation of the new concept of computer-integrated manufacturing, there is no formal, explicit definition of CIM. (Note: The author even refused to coin the acronym CIM as he felt that the world was "already burdened with acronyms.") Interestingly, CIM is also not defined in the "Computer Integrated Manufacturing Glossary" [18]. Still, a variety of definitions exist [19] and the viewpoints covered range from "integrated CAD/CAM systems" to "management of the manufacturing organization as part of a total business

system." A few of the definitions given for CIM are listed below:

    CIM is designed to fill the gap between high-produc-
    tion transfer lines and low-production NC machines.
    [20]

    CIM is a truly integrated CAD/CAM system encompassing
    all the activities from the planning and design of a
    product through to its manufacture and shipping. [21]

    CIM works on the premise that management should work
    to optimize the whole business process rather than
    individual functions or elements. [22]

    CIM is the integration of computer-aided design, com-
    puter-aided manufacturing and production management.
    [23]

    CIM is the link between corporate management and all
    engineering and manufacturing planning and opera-
    tions...a specialized form of information and image
    management in a computer environment. It builds on the
    principles of management information systems and ties
    together the use of different databases, process con-
    trols, management of logistics, schedules, and re-
    source utilization. [24]

Although, it is apparent that there cannot be a single, simple, correct definition for a complex concept like com- puter-integrated manufacturing, most of the existing defini- tions take a narrow, single-faceted view of CIM. Most common definitions view CIM as an "integrated CAD/CAM system," or as a system which uses the most advanced manufacturing technology. Other frequently used definitions regard CIM as something which affects whole organizations by computerizing the major organizational functions or by viewing the manu- facturing component as part of a total business unit. Most

written descriptions of CIM do not consider the influences external to the manufacturing portion of the organization, but researchers and practitioners have apparently begun to realize that the most important part of CIM is integration. Complete integration must encompass all aspects of the business – and must focus on cooperative management of the organization [19].

CIM is definitely not a single technology, but is instead a broad, integrated concept. Ideally, CIM incorporates innovative manufacturing technologies, such as computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), computer-aided process planning (CAPP), computer-aided production control, source data automation, numerical control of machine tools, robotics, automated material handling, computer-controlled flexible machining or processing systems, and manufacturing databases, in an integrated fashion within the structure of a manufacturing organization.

Regardless of the confusion regarding the definition of CIM, the concept is certain to gain momentum simply because of its potential benefits. Several of these potential benefits are listed below:

1. reduced manufacturing costs,

2. increased overall productivity,

3. improved product quality,

4. increased competitive edge and profitability,

5. significantly reduced inventories,

6. increased ability to respond to product mix changes,

7. increased market share, and

8. shortened order turnaround time.

To date, the CIM concept has only in isolated cases been fully applied. Instead, computerized bits and pieces of the CIM jigsaw puzzle are found here and there - often incorrectly touted as being total integration. Table 2.2 shows some of the manufacturing areas commonly computerized and often misrepresented as "full" CIM systems by their vendors.

2.3 CURRENT IMPLEMENTATION OF CIM

Computer-aided design, computer-aided manufacturing, computer-aided engineering, or any of the many other computer-aided advances of the recent past are examples of this piece-by-piece enhancement to manufacturing technology [7]. Each is a computerized application of an improvement in some particular portion of the total process. Each individual improvement, though real and important, is essentially a local fix and may or may not mesh productively with neighboring bits of technology. More often than not, it is one of the "atoms" which is upgraded, but without significantly improving the total "molecular structure."

FUNCTION	COMPUTERIZATION
Product Design	CAD/CAE, Group Technology
Process Planning	Group Technology, CAPP
Methods/Standards	Automated Work Measurement, Computerized Cost Estimating
Facilities Management	Computer-Aided Layout
Maintenance	Computer-Aided Preventive Maintenance, Automated Machine Diagnostics
Production	NC/CNC/DNC, AS/RS, AGV, Robotics, Machine Vision, Programmable Controllers, Factory Networks
Quality Control	Automated Inspection, Statistical Process Control
Production Management	MRP/MRPII, Inventory Control, On-Line Inquiry

Table 2.2:   Locally Computerized Functions in Manufacturing [16].

Typically, a human-powered or human-controlled task is replaced by a machine-powered or data-controlled mechanism. The task productivity improvement is both obvious and immediate. Unfortunately, the improvement to the overall manufacturing process is often negligible. For example, suppose the time required for packaging is reduced from one minute per unit to ten seconds per unit, a six-fold improvement. However, if the product arrives at the improved packaging

workstation behind schedule and is distributed (after packaging) in the same, pre-automation, less-than-efficient manner, little - if anything - has been gained. That is, because modernization is often confined to a small part of the total manufacturing operation, the net positive effect of the improvement is often minimized.

In order to have a broader, wider-reaching impact, the new mechanism must be coordinated with adjacent manufacturing areas insofar as input, output, speed, and performance are concerned. Unfortunately, such coordination is uncommon. The main reason for the coordination failure is that individual manufacturing units have not typically been designed to communicate outside themselves. Communication still takes place across the same borders that were originally established by "people-to-people data exchange modes" [25]. With the new systems, new information needs are apparent, and real-time information and powerful decision-support tools are available. The old methods speeded up are simply inappropriate.

Deere & Company's J.F. Lardner [26] described tremendous growth in the indirect labor and salary costs per unit of output over the past 15 to 18 years at Deere's production facilities. The increase in indirect labor costs at first appeared to result from large increases in the complexity of manufacturing, but further analysis indicated that the complexity had been unintentionally compounded by the use of a

"divide and optimize" theory. Lardner reported that a re-orientation toward a "total systems" viewpoint paid off with a 50% reduction in tooling costs, 10-15% reduction in total manufacturing costs, 15% increase in equipment availability, and 40% reduction in defective work and material. Lardner stated that a solution to the total manufacturing problem for Deere was found by "pulling together the pieces that have been so carefully separated over the past forty years."

All of these ideas point to the major problem facing the American manufacturing community of today, its failure to understand the new nature of manufacturing in the modern world. The strength of American manufacturing was at one time its thorough understanding of the manufacturing process and its ability to blend its pieces successfully. Those successes occurred when coordinating manufacturing processes depended almost wholly on "people-to-people data exchange modes." At present, much of American industry is still trying to operate in that same old person-to-person data exchange manner - but at a higher rate of speed, superimposing bits-and-pieces of modern manufacturing related computer technology on top of it. The net result is often something other than increased production.

According to Harrington [25], the structure of the sci-ence of manufacturing is the same, whether one is making airplanes, carpets, computers, paper clips, newspapers, or television sets. The same functions are performed and the

same managerial controls must be exercised. These functions and controls are invariant over time, so that regardless of when or in what stage of technological development one is working, the same principles apply. If this structure of manufacturing can be understood, it can be subjected to well-known methods of analysis and its parameters can be predicted, measured, and controlled.

The intent of the above discussion is to emphasize the crucial and growing importance of understanding and dealing with the whole of the manufacturing process - the continuum of manufacturing and all its interrelationships - not just its individual pieces, no matter how important they may be. Research programs in some of the other industrialized countries, such as the United Kingdom, have already recognized that the main goal of their manufacturing-related research endeavors should be to "examine manufacturing as a systems concept" [27]. Thus, it is becoming increasingly important to understand the relationships between manufacturing subsystems, as well as understanding the intricacies within these subsystems. For example, the research required to determine the components and interrelationships necessary to implement a successful scheduling system in a computer-integrated manufacturing environment should be of equal - or greater - concern to researchers as the development of a new scheduling algorithm.

2.4 PRIOR WORK

The idea of applying modeling and simulation to the manufacturing environment is not new. Since the development of simulation methodology, numerous models have been constructed to simulate various aspects of the manufacturing system. In fact, there may be so many that it is impossible to provide a complete list of all the attempts made so far.

During the literature review for this dissertation, one thing became clear; that almost all attempts made so far have fallen short of modeling and simulating the entire manufacturing environment at any level of detail. Almost all simulation programs reported were restricted to some aspect of production within the manufacturing environment (i.e., production planning and control or process planning). In some cases, inventory control functions were also included, but most of the manufacturing modeling efforts do not go beyond that [28,29,30,31,32].

Another fact which became apparent is that there are a variety of approaches applied to simulating the manufacturing system. Some of the earlier manufacturing modeling efforts were performed using batch computing approaches [33], but more recent model developments tend to rely on interactive computing methods. Recent efforts also include the use of graphical approaches in modeling [34]. The use of an expert systems approach to manufacturing subsystems modeling [35] is another clearly identifiable trend.

Still, at least to-date, no modeling effort has been completed which includes a comprehensive manufacturing organization's environment, even at a simplistic level. Almost all the models developed so far have taken a narrow, somewhat limited view of the manufacturing system. Many of these models contain significant complexity in one particular area of the manufacturing environment and often completely exclude other areas.

Some major simulation efforts, however, have come close to the idea of modeling the entire manufacturing system environment. One of the earliest simulation works relating to the manufacturing environment was presented by Krajewski, et al. through their Manufacturing System Simulator (MASS) [33], but its view is limited to the production/inventory system. MASS was developed to function in a batch processing environment.

Engelke, et al. built a generic software package for manufacturing modeling called Integrated Manufacturing Modeling System (IMMS) [34]. Input to IMMS is performed by placing predefined function symbols on a graph-like screen and by filling in screen-generated blanks to specify parameter values. IMMS uses a queueing network approach to modeling the manufacturing system. Although IMMS is a useful interactive simulation tool, it ignores all manufacturing organization functions other than production.

In 1986, IBM announced a simulation model for simulating

manufacturing scenarios using the GPSS language [36]. But the emphasis of this modeling effort was also placed on the details of production processing.

Crookall reported the development of a computer-integrated factory system combining the concepts of simulation and database [37]. But the Crookall model is limited to only two primary work areas (machine shop and assembly shop) and two secondary areas (raw materials storage and finished parts storage). This model represents an innovative approach to modeling and recognizes the importance of concurrent information flow in modeling the manufacturing environment, but it is apparent that the scope of the model is very limited.

Pruett initiated an effort to develop a comprehensive computer-integrated simulation model to provide engineering students with broader understanding of the manufacturing environment [38]. The current dissertation research which led to the development of MOSES was actually begun with this particular effort.

Recently, Lindeque and Kruger reported development of a training simulator for production management [39]. Although not touted as a computer-integrated manufacturing model, it takes a systems approach in developing the simulator and is a valuable step in the direction of developing a comprehensive model of the manufacturing environment.

As mentioned above, numerous expert systems approaches

have resulted in new models of the manufacturing environ-
ment. Some noteworthy effort in this area are Nof's "An
Expert System for Planning/Replanning Programmable Facili-
ties" [40], "Job-Shop Scheduling: An Investigation in Con-
straint-Directed Reasoning" by Fox, et al. [41], Lee and
Tse's "An Integrated Approach to Manufacturing Enterprise"
[35], Ben-Arieh's "Manufacturing System Application of a
Knowledge Based Simulation" [42], and "Expert System for
Industrial Facilities Layout Planning and Analysis" by
Kumara, et al. [43].

It is apparent that all of the above are addressing
specific parts of the manufacturing environment and are
mainly efforts to apply artificial intelligence/expert sys-
tem related techniques to an area of manufacturing. Lee and
Tse's approach [35] seems to emphasize the total manufactur-
ing enterprise and includes the information flow and deci-
sion support for various organizational components. But the
work is still in the research stage such that no specific
details are available.

There are several other "manufacturing simulators" which
have been commercialized. Some recent ones in this category
are XCELL+ [44], MAP/1 [45], and SIMFACTORY [46]. All three
concentrate on simulating manufacturing processes at the
shop floor level in varying degrees of detail, however, and
ignore the effects which their actions might have on other
areas of the manufacturing organization.

The research concern addressed by this dissertation focuses on the manufacturing environment as a whole. This research is concerned with modeling and analyzing the entire manufacturing organization in order to improve understanding of the total system and to make the contributions and inter- actions between the subsystems more evident. The development is completely modern, including a combination of computer- based simulation, information systems, database systems and concepts of intelligent simulation applied to the manufac- turing cycle.

The result of the research development effort is an interactive, manufacturing organization decision-support tool. It may be readily applied by managers, decision- makers, researchers, and students since its use requires no programming, modeling, or simulation skills. Only an interest in working with a simulated manufacturing organiza- tion and the ability to use a standard computer keyboard is required.

Chapter III

HYBRID MODELING APPROACH

Traditional approaches of modeling the manufacturing system and its subsystems have been through the application of mathematical modeling techniques, typically referred to as operations research methods. These techniques have generally been applied to individual manufacturing system components, such as production scheduling and inventory control. It is now being recognized, however, that a broad, multi-functional view of the manufacturing system, one encompassing the whole enterprise, is probably more appropriate [27].

Another series of trends in modeling, which have only recently become apparent, are movement away from strict reliance on calculation and movements toward more definition, away from purely mathematical models and toward formal descriptive models, away from oversimplified, haphazard approaches to system development and toward the use of structured analysis and design techniques. The trend results from a recognition that the former, mathematical-only view of modeling is too restrictive for application to all systems. This is not meant to imply that mathematical models are somehow "bad," but that they are sometimes inappropriately narrow, and that another type of model must be used.

The approach which was taken in this research effort to develop a computer-integrated manufacturing model incorporates a combination of the more traditional mathematical modeling methods and a simplified variety of the more recently developed expert system-like techniques, with both approaches coupled with information system and database concepts.

3.1 COMPUTER-BASED MODELING AND SIMULATION

Computer simulation has long been recognized as a powerful tool to study the behavior of complex systems which are mathematically intractable. Simulation is the process of designing a logical model of a real world system and conducting experiments with this model for the purpose of understanding the behavior of the system or of evaluating various strategies for the operation of the system [47].

Computer-based simulation typically utilizes digital computers in the above process. The system components: attributes, events, activities, and relations are described by a high-level programming language acceptable to a digital computer, as shown in Figure 3.1.

3.1.1 Modeling and Simulation Process

The flow chart in Figure 3.2 shows the systematic nature of a simulation study for a planned or existing system. Starting with the problem definition, the simulation objectives

```
┌────────────────────┐          ┌────────────────────┐
│MANUFACTURING SYS.  │          │ SIMULATION  MODEL  │
├────────────────────┤          ├────────────────────┤
│                    │          │                    │
│  * COMPONENTS      │          │ PROGRAMMING        │
│  * ATTRIBUTES      │────────▶ │ LANGUAGE:          │────────▶
│  * EVENTS          │          │ * DATA STRUCTURE   │
│  * ACTIVITIES      │          │ * SUBROUTINES      │
│  * RELATIONS       │          │ * ARITH/LOGICAL    │
│                    │          │   OPERATIONS       │
└────────────────────┘          └────────────────────┘
```

```
┌────────────────┐
│ COMPUTER       │
├────────────────┤
│ * EXECUTION    │
└────────────────┘
```
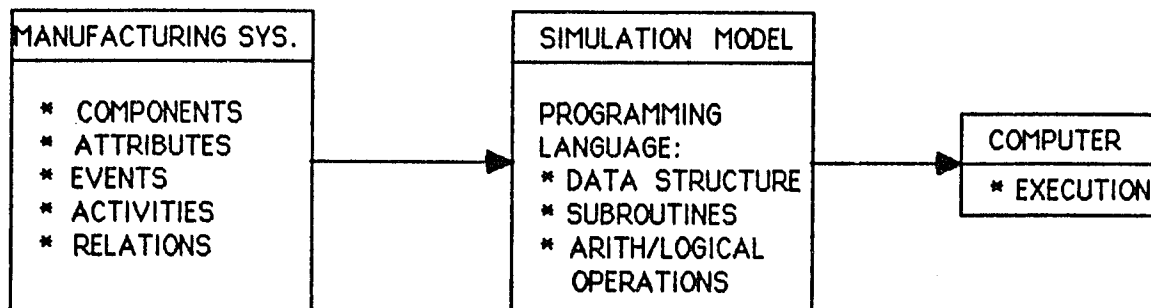
Figure 3.1: Computer-based Simulation

are determined. The steps of model construction and imple-
mentation, program verification, and model validation
follow. A valid model is one in which the behavior of the
model agrees with the behavior of the real system. In the
case of a planned system, true validation is possible only
if the results from a similar system are available. If not,
a comprehesive test of all model functions and the logical
verification of the results may be the next best alterna-
tive. After completion of the model development process,
simulation experiments can be planned and carried out. The
implications obtained from the analyzed simulation results
are then applied to the real system.
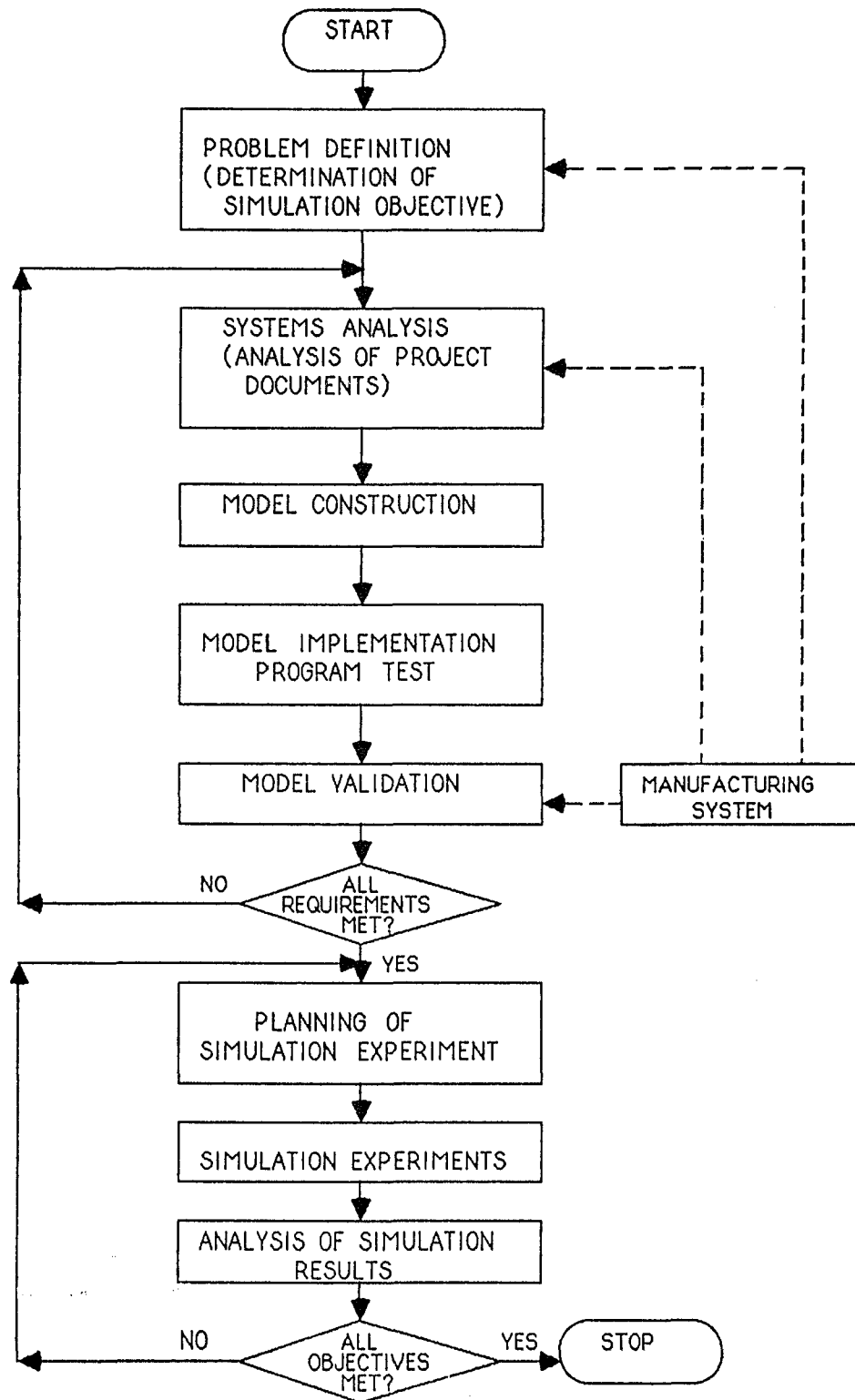
Figure 3.2: Modeling and Simulation Procedure

3.1.2 Modeling and Simulation in Manufacturing

Computer simulation is a frequently employed tool in various stages of manufacturing systems analysis. It has been used to provide additional understanding on such topics as machine loading and utilization, material handling, tooling management, total systems reliability management, and cell production control. An international survey [48] of the uses of computer simulation in the design of manufacturing systems showed the following aims:

1. to demonstrate feasibility of manufacturing plans, including layout, parts handling, tooling, and operations planning,

2. to minimize risks and learning time in actual manufacturing,

3. to optimize use of all resources and controls, particularly the establishment of production control logic and structure, and

4. to train key personnel and assist management in optimizing the system.

More specifically, computer simulation has been used to model various aspects of the manufacturing system at a number of levels [37].

Level 1, Corporate Level – including such aspects as factory demand, including market and corporate plans,

Level 2, Department Level – including such aspects as division, shop, or cell control, including loading, shift policies, reliability and systems management,

Level 3, Workplace Level – including such aspects as

machine and process cycle, including NC/DNC download, CAD/CAM, tooling, fixtures, palletizing, robot handling and loading transfer, and

Level 4, Operations Level - including such aspects as manufacturing technology, including quality assurance, adaptive control, process planning, and tool design.

Levels 1, 2, and 3 are generally simulated using "event-based" simulation and models. These are developed both as planning tools and as potential "program generator" for computer integration. Level 4 software is more process specific.

Still, one of the most valuable potential contributions of computer simulation lies in its capability to model the total manufacturing system [49]. A simplistic view of MOSES is that it is a computer-based, discrete-event simulation model of a complete computer-integrated manufacturing organization. Concepts of abstraction and simplification have been employed in building the model at a basic level of realism.

3.1.3   User-interaction in Computer Simulation

Current simulation technology involves the use of high-level computer languages designed to mimic the performance of the various actual operations by representing typical system elements, such as machines, queues, and servers with single, definitive statements [50]. Unfortunately, the present level

of simulation technology still involves the use of rather complex simulation packages. To use the simulation software correctly, an individual must have several specific prior abilities [51]:

1. an understanding of the technique of simulation,

2. strong computer programming skills, and

3. complete knowledge of the capabilities and limitations of the simulation software.

For the typical person needing to model a manufacturing system, the first of the above requirements is appropriate. One must understand what simulation is all about to effectively use the technique. Requirements two and three, however, are unnecessarily restrictive. Why must a person interested in analyzing the manufacturing system be a programmer? And, if his responsibilities are in manufacturing, why should he be forced to learn the intricacies of a simulation language?

MOSES was designed from this perspective. While MOSES users are expected to understand the principles of simulation, they need not have any simulation modeling experience, any computer programming skills or any knowledge of simulation software. MOSES is completely interactive, from model construction through system analysis, and while the MOSES user is in a real sense the developer of the model, no programming effort is required.

In a sense, MOSES represents a "spreadsheet approach" to simulation modeling. Like currently available computer spreadsheet packages, such as LOTUS 1-2-3, MOSES eliminates the programming details for the user and lets him concentrate on the analysis aspects of the situation. For example, the MOSES user can request that a sales forecast be prepared on all of the organization products using a three-period moving average. After viewing (and printing, if he chooses) the results of the new forecast, he can then request that another forecast be prepared using either different numbers of data periods for individual products and the same moving average technique or a completely different forecasting technique. This pattern of change, calculate, and view can be repeated indefinitely. While the MOSES user may eventually be satisfied with the results of a numeric forecast, he also has the ability to override the computed forecast values by typing in his experienced-based figures. All of these activities are much the same as those which are permissible via general-purpose spreadsheet software.

3.2   INTEGRATION OF DATABASE CONCEPTS

The total system view of manufacturing requires an information systems orientation, but with technological, tactical, and logistical control. The data must be available in suitable form for a variety of purposes within the integrated factory. Fast access and immediate information update are

required. In fact, the most important component necessary for the development of an effective computer-integrated manufacturing system is probably database management system (DBMS) software. A model which revolves around a central database architecture allows a range of related functions to be integrated into a timely, decision-oriented structure. Britton and Hammer [52] have emphasized the following advantages of database use in the manufacturing environment:

1. A DBMS simplifies and standardizes access to an organization's data.

2. One objective of a manufacturing system DBMS is to integrate the corporate database (by structuring formats, access techniques, and data relationships).

3. Use of a DBMS should reduce data redundancy.

4. A DBMS allows systems to be built in an evolutionary manner.

5. The data independence provided by a DBMS means that programs using it can access only the data items they require.

6. The concentration of file access logic in a DBMS offers significant benefits with regard to migrating to new computer hardware or operating systems.

The need to utilize some type of orderly data handling methods in performing computer-based modeling and simulation is fundamental. Since database technology is central to the implementation of CIM, it is logical to use the same database technology in the implementation of a CIM simulation model.

Historically, simulation languages have relied on arrays and pointer-driven lists for storing and manipulating data, but it is obvious that a DBMS can provide a powerful and flexible means of managing the wealth and diversity of data that must be generated and maintained in the life cycle of a simulation project [53]. This idea is not new. It was first proposed and used by Standridge and Pritsker [54] in the design of SDL/1, which integrated a conventional database management system with a state-of-the-art simulation software system.

A DBMS removes the burden of data administration from the simulation modeler. No longer does he have to worry about where or how data values are stored. Instead, the modeler simply calls for the data as it is needed and the DBMS provides it.

Another potential advantage of using a DBMS integrated with the simulation model lies in its capability to more efficiently handle data from a real organization, especially for storage and retrieval of data on-line. Figure 3.3 illustrates this on-line, real-time use of an integrated database/simulation system which is simultaneously available to many users.

MOSES is an interactive, manufacturing organization simulation model which includes a complex and sophisticated data storage, retrieval, and manipulation system. Given that its use requires no programming skills and no simulation lan-

DATABASE
MANAGER

DATA
GENERATOR

DEFINE/DELETE

SIMULATION
MODELER

LOAD, EDIT,
UPDATE

CENTRAL
DATABASE

RETRIEVE AND STORE
SIMULATION PROGRAM

CREATE STATISTICS
HISTOGRAMS

PLOT REPORTS

STATISTICAL
ANALYST

DECISION
MAKER
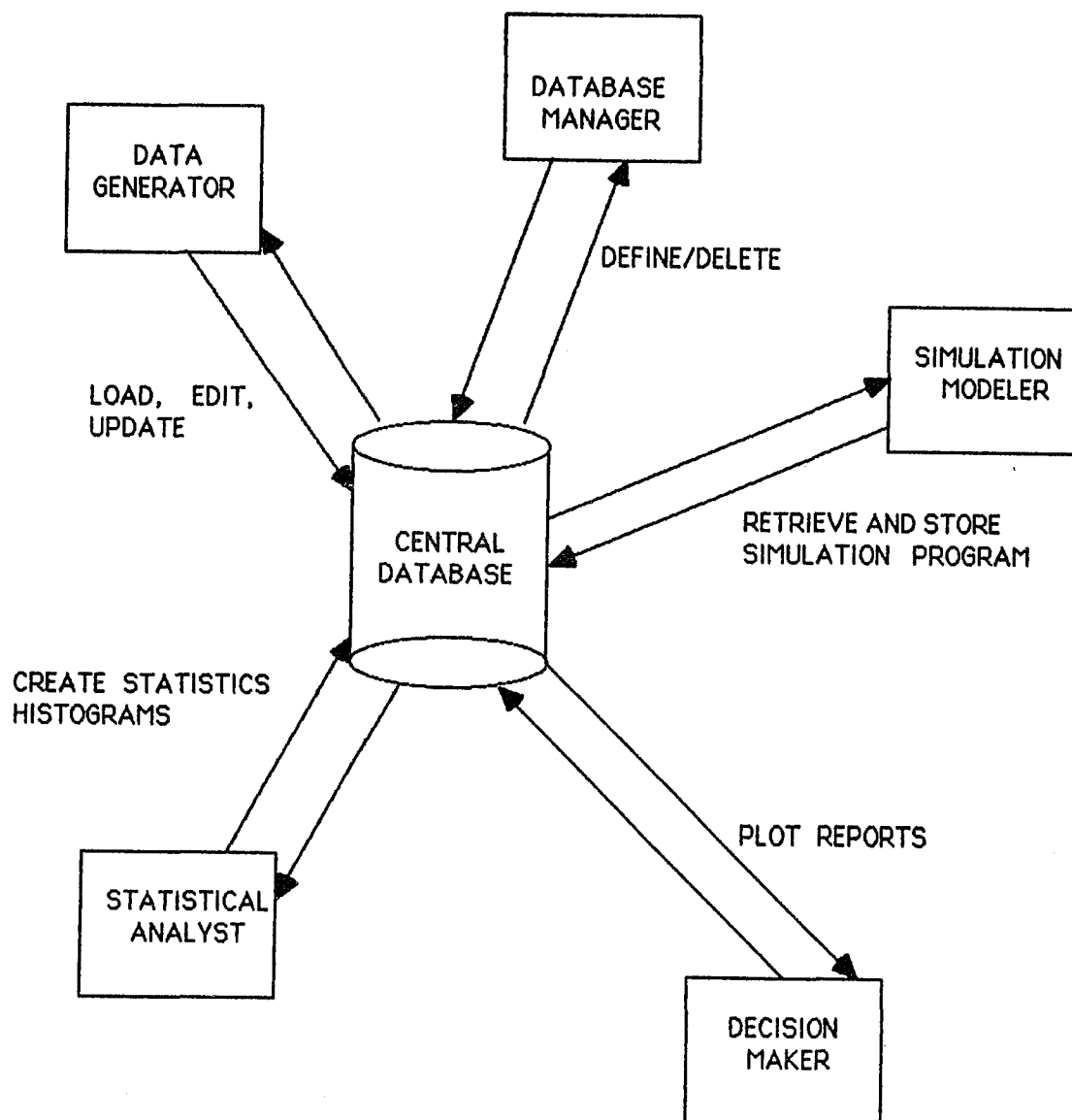
Figure 3.3: Integrated Database and Simulation

guage knowledge, it is indeed an unusual simulation software
package. But there is more.

3.3 INTELLIGENT SIMULATION

While many important results and insights into the working
of manufacturing subsystems have been obtained with the aid

of mathematical models, the literature of manufacturing research also contains numerous references to heuristical methods, or more formally, heuristics programming [55,56,57,58]. Researchers have found many situations which defy the approaches of mathematical modeling, but which can be readily modeled by heuristics or descriptive techniques.

The use of heuristics in modeling a system or subsystem leads to a related approach known as knowledge-based programming or intelligent simulation. Intelligent simulation, as opposed to numerical simulation, represents the logical structure of the environment being modeled through a series of facts and rules. Such an approach is well suited to modeling the logical connectedness and relationships which exist among the components of manufacturing subsystems. Such approaches are expected to open up broad new areas for simulation which to-date have been very difficult to model.

Because much of the knowledge we possess is based on experience, intelligent simulation techniques are frequently more appropriate than the more traditional numerical techniques. In fact, it is not surprising that researchers have found it difficult (if not impossible) to model the entire manufacturing system using only conventional modeling techniques. Intelligent simulation, which leans on the rather recently developed principles of expert systems, inherently provides explanations for its actions and decisions, a feature which would seemingly be a tremendous aid in the devel-

opment of a realistic manufacturing model as an interactive management decision-support tool.

One obvious problem with intelligent simulation is that it is a relatively new and still evolving concept, lacking both a formal definition and a standardized approach [59,60,61]. A few of the published efforts in the area of manufacturing systems are: "An Expert Manufacturing Simulation System" by Ford, et al. [62], "A Prototype Knowledge-Based Simulation Support System" by Hill, et al. [63], Moser's "Integration of Artificial Intelligence and Simulation in a Comprehensive Decision-Support System" [64], and Ben-Arieh's "Manufacturing System Application of Knowledge Based Simulation" [42].

As mentioned above, the concept of intelligent simulation is based on the knowledge-based/expert system approach. Michie defines an expert system as an attempt to "embody in a computer the knowledge-based component of an expert skill in such a form that the system can offer intelligent advice, and on demand justify its own line of reasoning" [65].

Most knowledge-based systems are designed to reason according to some logical rules and facts, and to eventually arrive at a conclusion or recommendation. In most cases, analysis is time-neutral; that is, it is conducted at a fixed point in time, and the variables are not allowed to fluctuate in value during the time of analysis. This is not a serious shortcoming in a knowledge-based system designed

to perform a medical diagnosis, but it becomes important if the system is used for making business decisions, where time is typically a crucial variable. For example, simply because of the effect of time, a dollar today is not the same as a dollar tomorrow. But even this simple concept is difficult to capture in most expert systems.

Along the same lines, expert systems are not generally able to look into the future before reasoning their way to conclusions to be applied today. Keeping this shortcoming in mind, the reasoning ability of a knowledge-based system can be combined with the capabilities of computer simulation to predict the values of complex sets of variables over time, analyze the simulation output, draw appropriate conclusions, and suggest necessary actions – in essence, to serve as management decision-support tools.

In terms of the manufacturing environment, knowledge-based systems can be envisioned, for example, as enabling the computer to assist manufacturing managers in their judgemental and stretegic roles, as well as with routine matters (e.g., record keeping and preprogrammed responses to a predictable range of input). Because the knowledge base used is derived from the expert or experts who have "programmed" the system with their experience and know-how, control strategies based on these "expert" thought patterns should follow well-understood or preferred approaches.

There is no intent here to imply that it is absolutely

necessary to model manufacturing systems through the techniques of knowledge-based simulation only. However, it is apparent that some of the tasks inherent in a computer-integrated manufacturing environment, such as production planning and scheduling, can be modeled using a knowledge-based system combined with traditional simulation modeling techniques. Such a use of knowledge-based simulation allows the decision maker to explore alternatives, make changes to the existing schedule, and to search for the "best" schedule given current conditions [60].

As such, MOSES was developed as a hybrid system which utilizes, when appropriate, either traditional quantitative modeling tools or more recently developed knowledge-based techniques. More specifically, MOSES is composed of heuristical algorithms as well as the more traditional mathematical algorithms.

In addition, MOSES utilizes to a limited extent the expert system-like concept of reasoning based on facts and rules. In particular, this approach is used to make recommendations concerning possible changes in a computer-prepared production schedule. MOSES presents before-the-fact results and alternatives for action. Managers then have the option of modifying the schedule and/or the resources. This general approach will also be useful in future enhancements to the model. In fact, it may be that true expert systems will be incorporated within MOSES as the model evolves.

Chapter IV

MOSES: CONCEPTUAL DESIGN

This chapter presents the conceptual design of MOSES. The term "conceptual design" is at least partially a misnomer. A more descriptive term might be "conceptual philosophy." Either way, it means the ideas behind the creation of a particular system - why it was designed the way it was designed. The conceptual design serves as the foundation of any simulation model.

The breadth of functions and complexity and dynamics of the structure make understanding the modern manufacturing organization difficult. This complexity has been both simplified and further compounded by the rapid development of computer technology which has had a major influence on the manufacturing environment. This computer-based technology has resulted in the era of management information systems within the manufacturing environment. To model the total manufacturing environment is a complex task. There are several reasons for this.

1. The functions of production equipment, supporting activities, and workers are dynamic and diverse and interact in complicated ways which are often not readily apparent.

2. The subdivision of a manufacturing organization's functions promotes localized, self-serving views of success. That is, functional areas (e.g., marketing) may be more concerned with local success than with overall organizational success. Also, system views may be distorted by the fact that not all functional areas are equally well defined. For example, the activities of shop floor production may easily be observed, whereas decisions leading to marketing strategies may be noticed only if the consequences are negative.

3. Knowledge about a given manufacturing-related system may become suddenly obsolete as the result of fast-changing product and production technologies. This makes thorough understanding of the system difficult simply because of a lack of "familiarity time."

In order to develop a manufacturing simulation model which makes sense in this type of environment, it is important that some valid assumptions are made which will simplify the system interrelationships without destroying the nature and logical structure of the system. A manufacturing environment, though a complex entity, can be visualized as being composed of four main functions:

1. Marketing

2. Inventory

3. Production

4. Accounting

The presence of these four functions in varying degrees of prominence is basic to all manufacturing organizations. While the names and functional subgroupings chosen for use in MOSES may be argued, the functions placed within these four areas are not arguable. They are simply the functions which must be performed within a manufacturing organization. Figure 4.1 shows the logical structure of MOSES. Part of this chapter describes the individual functions which make up the four functional areas.*

Another of the important aspects of the conceptual foundation of MOSES is that it recognizes the right-to-override of the manager/user as a key element in the modeling process. That is, a MOSES user can change or override the parameter values computed within MOSES using mathematical or heuristic algorithms whenever he chooses to do so. This

----

* The functions of design and engineering, which affect the bills of material and production processes, have been excluded from direct inclusion in this first generation version of MOSES – as a matter of simplification. Bills of material can be changed manually and production processes have been included at a level of detail such that changes at the machine level of the production process are handled by modifying production parameters (e.g., production rate per hour), which does not affect the model structure.

MOSES MENU STRUCTURE
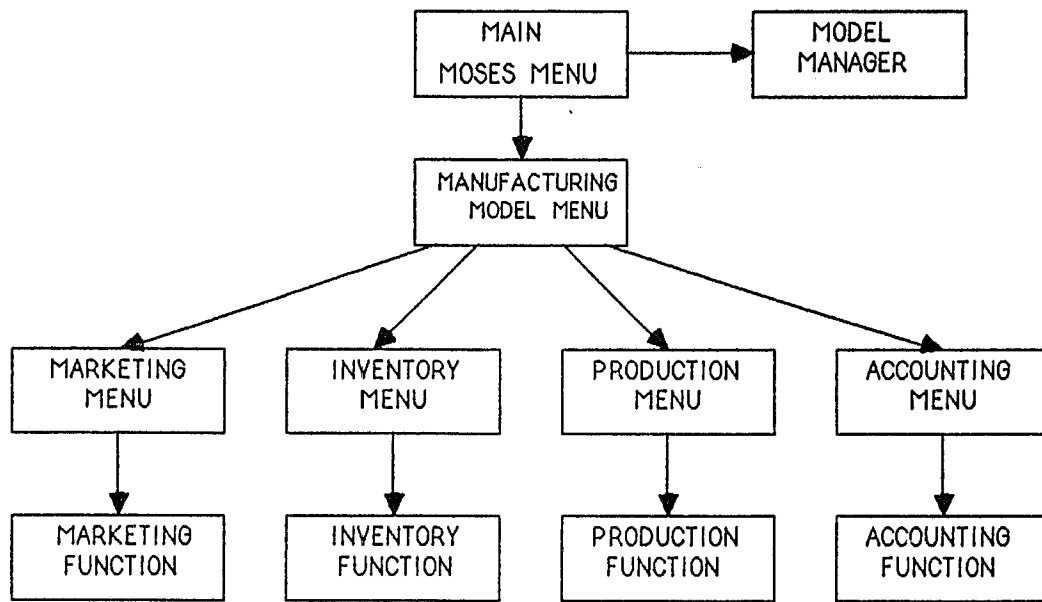
MOSES PROCESSING STRUCTURE
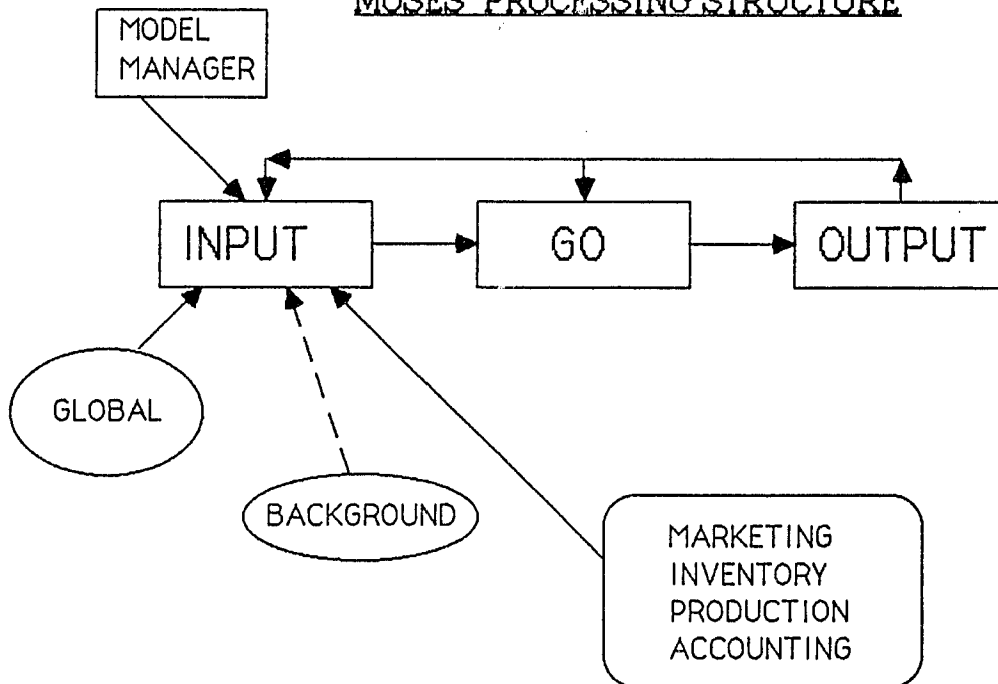
Figure 4.1: Logical Structure of MOSES

rationale is introduced with the argument that managers in a manufacturing environment should utilize all of the tools at their disposal (e.g., mathematical models for forecasting and inventory control), but that these modeling techniques are limited by their narrow views of the system. For example, all mathematical sales forecasting approaches use data from past sales periods. However, none of the approaches can measure the impact that a new piece of legislation might have on actual sales. Only a knowledgeable, intelligent, involved manager should have the opportunity to modify values set by such an automated decision process.

Shown below are three of the most important general assumptions made in conceptualizing the first version of MOSES. (Note: A complete list of assumptions is provided in Appendix A):

1. The model should work with any number of independent products within a manufacturing environment having limited production capacity and limited levels of raw materials. (Note: The number of products which MOSES can handle is limited only by the disk storage space available.)

2. Each product should have its own bill of materials. Each bill of materials may be composed of purchased parts, fabricated parts, and subassemblies. The fabricated parts (which may be

included within one or more subassemblies) are manufactured within the organization's production facility using raw materials purchased from external vendors. Therefore, fabricated parts have, in effect, their own bills of material. Subassemblies may be purchased in an already-assembled form (e.g., the ballpoint/tube/ink assembly in a ballpoint pen) or may be made up of a combination of purchased and fabricated parts. Purchased parts are obtained from external vendors.

3. Production processes consist of parallel or grouped manufacturing facilities and assembly lines. These groups manufacture and assemble both finished products and fabricated component parts. This means that MOSES is not concerned with the problems associated with product mix.

Simulation models have traditionally been composed of three parts: (1) an input section, (2) a modeling section, and (3) an output section. The input section includes a few global (i.e., housekeeping) values, such as the simulation start and stop dates and the values of one or more random number seeds, as well as the process-related input parameter values. The modeling section contains the simulation modeling logic. The output section includes statistics in table

and chart form which allow the modeler to evaluate and analyze the particular situation in question. The conceptual design of MOSES uses an extension of the traditional simulation structure, including each of the three standard simulation program parts. The conceptual view of each of the three sections is discussed next.

4.1 THE INPUT SECTION

As a result of the breadth of the system being modeled (i.e., the manufacturing organization), the input portion is quite extensive. Because of this fact, the main MOSES menu is really a file manager, allowing users to define new manufacturing organizations and able to retrieve previously defined manufacturing organization environments. Although the physical aspects of the model are described in detail in Chapter 6, a look at the model's first two menus is helpful in understanding the conceptual design.

Figure 4.2 shows the layout of the Main MOSES Menu. As is apparent when viewing the menu, besides having the capabilities of working with "Existing" (i.e., previously defined) organizations and the ability to "Add" new organizations, users also have the option of working with an "Example" organization and of "Deleting" previously defined organizations. The menu is mentioned at this point because it is an integral part of the model's input process.

Figure 4.3 shows the layout of the Manufacturing Model

```
┌─────────────────────────────────────────────────────────────────────┐
│ ┌──────────────────────◀MAIN MOSES MENU▶──────────────────────────┐ │
│ │                                                                  │ │
│ │   Example        Existing        Add        Delete       Quit    │ │
│ │                                                                  │ │
│ └──────────────────────────────────────────────────────────────────┘ │
│                                                                       │
│          ┌────────────◀Existing▶───────────┐                          │
│          │                                 │                          │
│          │ ABC Pencil Co., Shreveport, LA  │                          │
│          │ XYZ Penmanship, Inc., Baton Rouge, LA                      │
│          │                                 │                          │
│          │         Option 1  of  2         │                          │
│          │                                 │                          │
│          └─────────────────────────────────┘                          │
│                                                                       │
│ ┌──────────────────────◀EXPLANATION▶──────────────────────────────┐ │
│ │ Work with a Previously Defined Manufacturing Organization        │ │
│ │ Select ABC Pencil Co., Shreveport, LA                            │ │
│ ├──────────────────────────────────────────────────────────────────┤ │
│ │    Help        Horizontal        Vertical        Select          │ │
│ │    <F1>           ↔                 ↑↓            ↵               │ │
│ └──────────────────────────────────────────────────────────────────┘ │
└─────────────────────────────────────────────────────────────────────┘
```
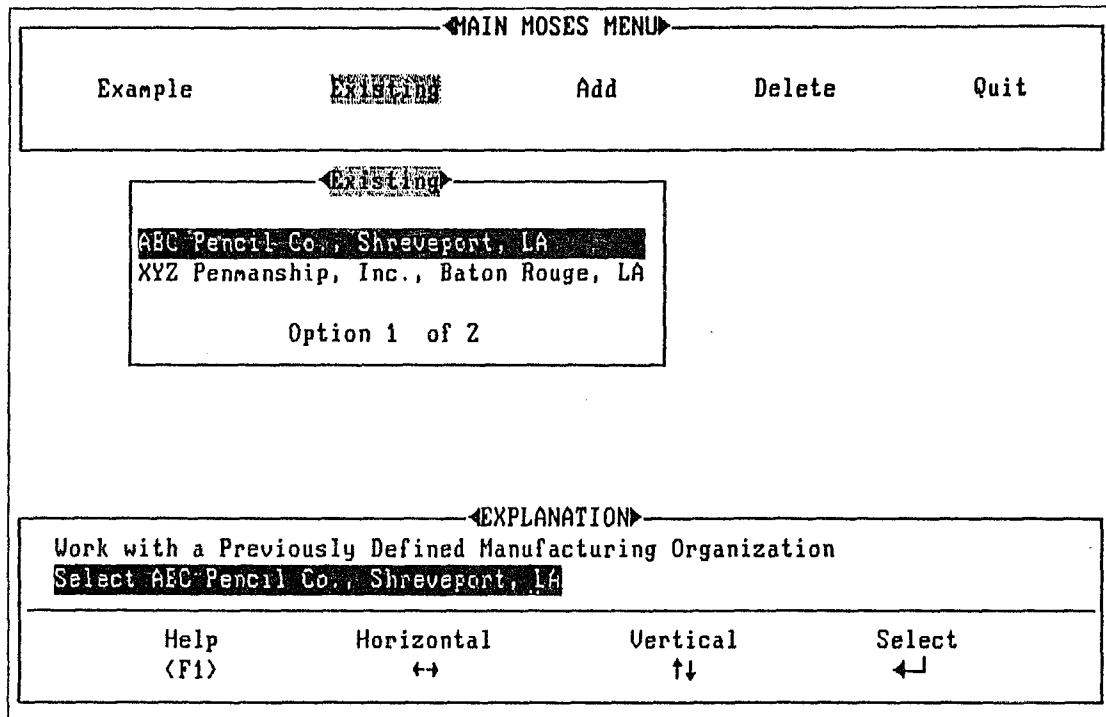
Figure 4.2: Layout of Main MOSES Menu

```
┌────────────────────────◀MANUFACTURING MODEL MENU▶──────────────────────┐
│ ┌──────────────────────────────────────────────────────────────────┐  │
│ │  Global      Background      Input      Go      Output     Quit    │  │
│ └──────────────────────────────────────────────────────────────────┘  │
│                                                          ┌───────────┐ │
│                                                          │ Marketing │ │
│ ┌──────────────────┐   ┌──────────────────────────────┐ │ Inventory │ │
│ │ Simulation Dates │   │ Inventory List, Finished Product│ Production│ │
│ │ Random Number Seed│  │ Inventory List, Fabricated Parts│ Accounting│ │
│ │ Reporting Interval│  │ Inventory List, Purchased Parts └───────────┘│
│ └──────────────────┘   │ Inventory List, Raw Materials                │
│                        │ Bills of Material, Single-Level              │
│                        │ Bills of Material, Where-Used                │
│                        │ Raw Materials, Where-Used                    │
│                        │ Raw Materials, Vendors                       │
│                        │ Purchased Parts, Vendors                     │
│                        │ Sales History, Finished Product              │
│                        │ Current Sales Forecast, Product              │
│                        │ Order Profile, Finished Product              │
│                        │ Backorder Filling, Product                   │
│                        │ Production Parameters, Product               │
│                        │ Production Parameters, Fab Parts             │
│                        └──────────────────────────────┘               │
└────────────────────────────────────────────────────────────────────────┘
```

Figure 4.3: Overlaid Layout of Manufacturing Model Menu

Menu. This menu follows the Main MOSES Menu once an organ-
ization's structure is selected (via the "Example" or
"Existing" options). The first three options on this menu -
Global, Background, and Input - are all in some way a part
of the simulation input process. Global parameters include
the simulation's start and stop dates, the random number
seed for this simulation run, and a parameter indicating how
often the user wants to examine the simulation's results
(e.g., daily or weekly or monthly). The Background option is
strictly a window providing a view (i.e., no input or
changes are allowed in this section) into the parameters
defined on the Main MOSES Menu. Fifteen separate reports are
presented, including such topics as Finished Products
Inventory and Finished Products Bills of Material. By
selecting the Input option, the user is really viewing a
third-level menu which includes the manufacturing organiza-
tion's four functional areas - Marketing, Inventory, Produc-
tion, and Accounting.

Figure 4.3 presents an overlaid view of the Manufacturing
Model Menu. The figure shows the suboptions for each of the
first three menu choices. Selection of any one of the four
Input options takes the user to a submenu for that particu-
lar function. Within the limits set for the particular
function chosen, the user can view the current setup, enter
new values and make changes to parameters whose values have
already been specified.

If the modeling section can be referred to as the heart of the simulation model, the Input section of the Manufacturing Model Menu must surely be the brain and the hands. It is through this section that the user's managerial expertise and preferences are entered into the model.

The basis of the modeling approach is that once the required subset of input values has been defined, a simulation of the manufacturing environment can be performed. There is nothing new about this approach to simulation modeling (although this particular manufacturing simulation model is, of course, new). However, the essence of the MOSES approach may be understood at this point. Before beginning the simulation process (or during the simulation process), the user has the opportunity to play "what if" in a variety of currently defined situations in an effort to determine the values he wishes to use or to fine-tune those values.

For example, when the manufacturing organization's data is loaded, a sales forecast is automatically computed for each product using historical sales data for those products. The default forecasting technique used by the model is the moving average method with the number of periods equal to one. Through the Forecast option of the Marketing section under Input, users can employ a "spreadsheet like" approach to perform sales forecasting using the moving average method with other numbers of periods and can also choose different mathematical forecasting tools to produce a forecast. A

measure of how "good" each forecast happens to be is shown by the "Root Mean Squared Error"* for the data provided. This approach means that the user has the opportunity – for this particular situation – to use any one of several mathematical approaches to prepare individual product forecasts.

But there is more. The user then has the opportunity to override any or all of the numerically prepared forecast values. That is, because the user (as manager) may have knowledge and insight which the mathematical model lacks (e.g., what happened recently in the stock market), he may choose to override the computed values, preferring instead to trust his own judgement.

If the user decides to run the simulation at this point, a production plan based on the forecasted sales is automatically computed. The model then tries to prepare a production schedule based on the desired "planned" quantities but restricted by the production capacity of the manufacturing facility and the availability of the raw materials and component parts. In fact, it often occurs that because of part or material shortages or facility limitations, it is not possible to schedule the exact number of units requested by the production plan. If this determination is made auto-

---

*

$$\text{Root Mean Square Error} = \sqrt{\sum_{i=1}^{n} (\text{actual sales} - \text{forecasted sales})^2}$$

matically during the running of the simulation, a Shortage Report which lists the reasons is produced. For example, the Shortage Report might say that part number 1005, used in the production of product number 3, was 250 short of the number required and that a lesser number of products were actually manufactured. This is standard simulation methodology — using the simulation process to find out what would happen under a certain set of conditions.

However, the conceptual design of MOSES provides the user with another earlier option. Instead of finding out about the problem after the model has been run, the user can find out before. After setting up a group of product forecasts, the user can then (through the Production option of Input) ask MOSES to compute a production plan and schedule. After the schedule has been computed, the user may then examine the schedule and the Shortage Reports and, before the fact, take appropriate action — which may or may not mean quickly obtaining the parts on the Shortage Report. For example, if the user learns that he will not be able to produce product number 3 because he is out of stock of required component part number 1005, he could — before beginning the simulation — "buy" (i.e., increase) the number of parts needed, add those parts to inventory, and then begin the simulation. He might make this decision after determining the price of the components, checking on their availability, and finding out how soon the components can be delivered.

The parts acquisition process would be performed manually (i.e., number of parts in inventory increased) - and the expenses incurred by that purchase would have to be entered manually through the Payables option of the Accounting section, but the realities of managing in a real-time computer information system environment would have been preserved. That is, some decisions must be made by managers and some actions must be performed manually, regardless of the degree of manufacturing automation.

4.2 THE MODELING SECTION

The modeling section contains the simulation modeling logic. MOSES is different from standard simulation modeling languages (such as GPSS, SLAM, SIMAN, and SIMSCRIPT) in that it uses a database management system to handle the model's data rather then other types of data storage methods. There are several advantages to this approach. One, the program statements which perform the data retrieval and storage functions are quite simple. Two, the fact that the data - input data, in-process data, and output data - is stored in database files allows it to be accessed readily. (Note: More on this benefit in the section on output.) Three, the database files permit the same set of data to be arranged in various ways and viewed in entirety or in part as is appropriate.

The model is also unusual in that it allows manual intervention. Both before and during the running of the simula-

tion model, MOSES users have the opportunity to modify the course of the simulation, if they wish, or to let the simulation run to completion using a more nearly standard simulation methodology.

MOSES simulates any manufacturing environment, requiring only that the organization be defined through a series of input values. As such, the "development" of the model requires no programming and no simulation modeling ability. MOSES is certainly unusual in this regard.

In combination, the above described simulation features which MOSES possesses make it unique - especially when applied to the entire manufacturing organization. Still, there is an additional feature of MOSES which is distinctly different from other simulation approaches. That feature is the hybrid nature of the MOSES system.

Traditionally, simulation models have been applied in situations that could not be described by mathematical models or to verify the accuracy of mathematical models. For example, while mathematical models have been developed for a variety of inventory situations. Only simulation models have been developed to analyze the more complicated inventory systems. The reason, of course, is that the complexity and stochastic nature of the arrangement made the development of the mathematical model either extremely difficult or impossible. MOSES is based on the idea that mathematical models should be included within the simulation system when-

ever possible, but that the lack of a mathematical model does not prevent the situation from being addressed. In such cases, heuristic (often non-optimal) problem solving techniques are employed. And, as was discussed at some length in the previous section, the MOSES user (prior to the simulation's beginning and at intervals within the simulation process) has the right to override values calculated by any of the methods.

It is also important to keep in mind that MOSES is intended to simulate an information-rich environment. Such an environment may be differentiated from an information-poor environment primarily by the time required to find out what is going on throughout the manufacturing organization. For example, traditional inventory models are based on some estimate of future product demand (either deterministic or probabilistic), order cost, carrying cost, and possibly backorder cost. A mathematical statement including these parameters is optimized with the results including a reorder point and reorder quantity. Such an approach made sense when it took days or weeks to determine what the actual demand figures really were, at which time adjustments could be made. This view typifies the approach taken in an information-poor environment.

However, a different approach is appropriate in an information-rich environment. Using the same inventory-based situation described in the previous paragraph, suppose that

the organization knows instantaneously each time a product is ordered, rather than finding out about it a week later. This "early warning" allows the organization to make frequent adjustments, place orders when supplies are needed, and increase or decrease production in a timely, responsive manner, depending on what "input signals" it receives. In other words, the economic-order-quantity-approach of the past loses its appeal (at least to some extent) in an information-rich environment.

On the other hand, if for some reason the instantaneous information system is out of commission, the previous modeling approach will produce an orderly, if not optimal, existence in the interim period.

Possibly the most important contribution made by MOSES is its ability to provide multiple views of the manufacturing environment both before and during simulation processing. (Note: In fact, the desire for multiple views was the original basis for the development of MOSES.) Since departments within an organization are often placed in contention with each other, it is simply not logical to expect them to truly cooperate. For example, if the goal for the organization's inventory function is to keep minimum inventory levels (no doubt, a worthy objective) and if the organization's production function goal is to maintain a steady production work load (also a worthy objective), there is a potential built-in conflict which is sure to surface if the product mix

changes suddenly because of a changing market. In other words, inventory might justifiably, even "optimally," have zero raw materials and zero component parts on hand of the types necessary to produce the product which marketing wants production to manufacture.

The structure of MOSES is such that it allows the current situation, even <u>during</u> the simulation run, to be viewed from each of four perspectives – marketing, inventory, production, and accounting.

While MOSES does not solve the problem of a contentious environment, the information it provides is a necessary first step in addressing the problem. That is, MOSES provides the opportunity for the manager in charge of one function (e.g., inventory) to see the impact of his policies on the organization's other major functions (e.g., marketing, production, accounting).

4.3 THE OUTPUT SECTION

The purpose of a simulation model's output is to provide an appropriate measure of the organization's performance so that the user can evaluate and analyze the particular situation in question. The approach taken in the conceptual design of the MOSES output system is much broader than that taken by traditional simulation modelers. This section describes the approach taken by MOSES.

First, because of the fact that MOSES users can examine

the simulation program's output during the running of the simulation as well as at its end, at least part of the MOSES view regarding output is somewhat different from the norm. Traditionally, simulation modelers examine the results of the simulation run after the completion of that run.

Second, the MOSES view regarding output includes the user's right to examine the situation, as well as the re-sults. For example, at the end of the seventh day of a 30 day simulation run, the MOSES user might be as interested - maybe even more interested - in knowing how well the inventory and production functions have been able to coordi-nate their activities as he is in the profit made on a particular product. The reason for this view is that good managers know that if you take care of the process, the results tend to take care of themselves. Our concern with "rewards," even in the seemingly legitimate form of concern regarding profits, is a symptom of an unhealthy, short-term view of success. As such, MOSES users should examine status indicators both through the standard output section of MOSES and by viewing the situation through each of the function areas.

Third, the by-functional-area view of the current situa-tion is particularly important. But, it might be argued, would it not be better to locate all of the output in one place? That would certainly make viewing simpler. The output section in a sense does show all the "output" in one place.

The point being made here, however, is that MOSES users need to "stand in the shoes" of each of the functional area managers, to see the situation through the limited, less-than-objective window which results from being responsible for a particular function. After that has been done, MOSES users can then better understand the statistics provided in the standard output section. (Note: The fact is that each of the functional-area managers are actually seeing restricted views of the same database files. The ability to provide restricted access, to show or not show individual fields, is one of the primary advantages of using a DBMS in conjunction with a simulation model.)

Four, the information provided in the output section is both standard and non-standard. It is standard in that it provides output categories which measure performance, both in terms of dollars and otherwise. It is non-standard in that the reports are separated from one another and may be viewed and printed individually.

In summary, the MOSES view of the output needs of a simulation modeler is different from most similar situations, but the reasons for these differences are both logical and positive.

Chapter V

MOSES: FUNCTIONAL OVERVIEW

This chapter discusses many of the important details in the functional design of MOSES. In fact, the bulk of the details are a part of the Input section of the MOSES Manufacturing Model Menu, although they are used throughout the simulation process, not just in the beginning. The comments are organized around the four functional areas: Marketing, Inventory, Production, and Accounting.

5.1 MARKETING FUNCTION

The marketing function is the driving force behind the success of a manufacturing organization. Its primary function is to create and stimulate demand for the organization's finished products, sell the products to customers, and provide after-sales service. Input from marketing serves as a source of information used by production in preparing the production plan and the master production schedule. In simplest terms, marketing consists of two subfunctions - forecasting and sales. Figure 5.1 presents the marketing function and the associated databases. All the assumptions which have been made in conceptualizing this function are included in Appendix B.
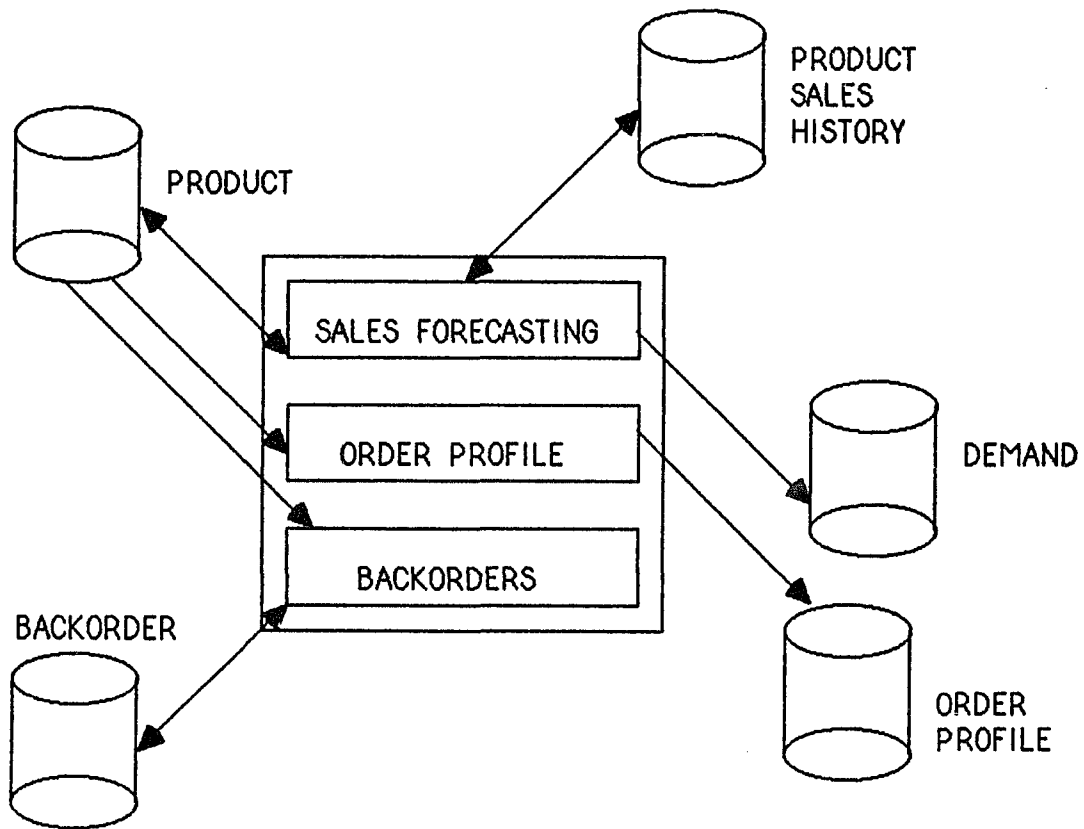
Figure 5.1: Marketing Function in MOSES

5.1.1 Sales Forecasting

Sales forecasting is essentially a prediction about a product's future sales based on the product's sales history. A complete sales forecast includes estimates of the quantities of each finished product that will be demanded by customer in some future time period. As such, it is the starting point for planning production resource needs (men and machines), operating budgets, and material needs. The forecast, however, is not in itself a commitment to produce any

specific number of products.

A forecast that is too low is likely to result in delayed shipments, lost sales, overloaded production facilities, and unnecessary extra costs (e.g., for such items as overtime and expediting). A forecast that is too high can be just as bad, leading to a pile-up of finished goods inventory, unnecessary production expenses, and underused facilities.

There are several numeric methods that are commonly employed in sales forecasting, but the objective is always the same – to be as accurate as possible regarding future product demand. There are two forecasting methods which have been included in the initial version of MOSES, but there are plans to include more in future versions.

The first method is known as the n-period Moving Average method. With this method the only variable which can be changed by the user is the number of moving periods of data used to find the average. A one-period moving average is the method's default period length. It uses the last period's actual demand as the forecasted value for next period's demand.

The second method is known as the Single Exponential Smoothing method. Single Exponential Smoothing includes two parameters whose values can be changed by the user. The parameters are the weighting factor (alpha) and the trend factor (beta). Output from both of these two methods is produced in the form of a sales forecast for each product

the next forecasting period. Each forecasting calculation also includes an associated "root mean squared error," which represents a measure of the accuracy of the forecast. The Root Mean Squared Error is calculated by applying the forecasting method chosen to the product's sales history data.

The user can interactively and selectively employ each method. By changing forecasting methods and parameter values, the user can try to minimize the forecasting error. The sales demand forecasting goal, which is the same regardless of method employed, is to generate forecasts which will accurately predict future finished product demand.

The product history database stores the actual past sales figures for each individual product over a specified period of time. These histories are used to prepare subsequent sales forecasts for each product for the next forecasting period. The length of the forecasting period is, by definition, the same as the length of the data period in the product history file. For example, if data is stored in 30-day data periods, subsequent forecasts will be for 30-day periods. Forecasting parameters (e.g., number of moving periods) for each individual product are stored in the product database.

5.1.2 Sales and Customer Orders

Sales (customer orders) of finished products drive the manufacturing organization. Without sales, the manufacturing

organization will cease to exist. Customers judge an organization not only on the quality and price of its products, but on how well their orders are handled, how responsive the organization is to their orders and after-sales service.

Customer orders can arrive in many different ways - directly from the customer by mail or phone, or indirectly through salesmen, distributors, or manufacturer's representatives. But regardless of how the order arrives, the organization should be ready to fill the order as soon as possible without losing the customer's current or future business. MOSES is designed based on the philosophy that through the integrated computer-based information flow, incoming orders are conveyed to order processing immediately and customers expect to have their orders filled immediately. Thus, MOSES tries to fill an order as soon as it is received, but if it cannot fill a particular order, it makes note of that fact and backorders for future delivery.

The sales patterns are stored in the order profile database. A typical order profile for a product consists of two types of parameters, those which describe the time between order arrivals and those which describe the order quantity for any given order, plus the distributional forms which describe each type. The marketing manager has control over the order profile specifications for each individual product. These figures reflect the MOSES user's judgement about the product's future sales pattern. Of course, part of the

judgement factor depends on the confidence he has in the organization's strategy of advertising.

5.1.3 Backorder Policy

Marketing is responsible for making sure that all customer orders are filled to the customer's satisfaction. There can be many complex measures of marketing's performance in this regard, but one of the most important effects marketing can have on the operating performance of the organization is the servicing of customer orders when there is an insufficient quantity of finished products on hand. Although marketing is not necessarily responsible when an order cannot be filled immediately, the marketing function probably has the best understanding of customer behavior under such circumstances. As such, the MOSES marketing manager has the prerogative to set the organization's backorder policy.

The backorder policy results from the less-than-situation in which an order arrives but cannot be completely filled. When this occurs, one of four options follow:

1. The entire order is backordered for delivery to the customer when the products have been manufactured.

2. The product available is provided to the customer immediately and the remainder of the order is backordered, to be delivered when the products are

manufactured.

3. The product available is provided to the customer immediately, but the remainder of the order is lost. That is, the customer goes elsewhere for the remainder of his order.

4. The entire order is lost.

Setting the backorder policy means that the manager must specify the probabilities associated with each of the four options - for each product. For example, suppose that in an intensely competitive environment all orders for a particular product that cannot be filled immediately are completely lost. The associated probabilities, which comprise the organization's backorder policy for the product, are 0.00, 0.00, 0.00, and 1.00.

5.1.4 Forecast Modification

A marketing manager may have a significant amount of experience in the actual marketplace. As such his experience may allow him to prepare a sales forecast based on "market feel," as well as sales history data. For this reason, MOSES allows the marketing manager to change or override the forecast prepared by a particular mathematical forecasting method. This may be accomplished through the "Modify" option of the Marketing Menu.

5.2 INVENTORY FUNCTION

Inventory is one of the primary assets of a manufacturing organization. It represents money in "hard good" form, since it cannot be used in any other venture. From the investment (i.e., liquidity) point of view, the ideal situation would be to carry no inventory. This point of view is the basis of what is known as the "Just-In-Time" (JIT) production and inventory policy. In fact, one of the advantages expected to accrue from the implementation of a CIM system is a reduction in all types of inventory. But some level of most types of inventory is an absolute necessity, since it must provide a cushion against sudden changes in customer demand or late deliveries from vendors.

The inventory function has basically two objectives, namely inventory accounting and inventory planning. Inventory accounting is the record keeping aspect of the inventory function. It is essentially responsible for keeping track of such parameters as available stock, quantity on order, and quantity in process. Inventory planning deals with decisions such as when to order, what to order, and how much to order.

The MOSES Inventory Menu has several subfunctions: product, materials, shipping, purchasing, and receiving. Figure 5.2 presents the inventory function and its associated databases. All the assumptions which have been made in conceptualizing this function are included in Appendix C.
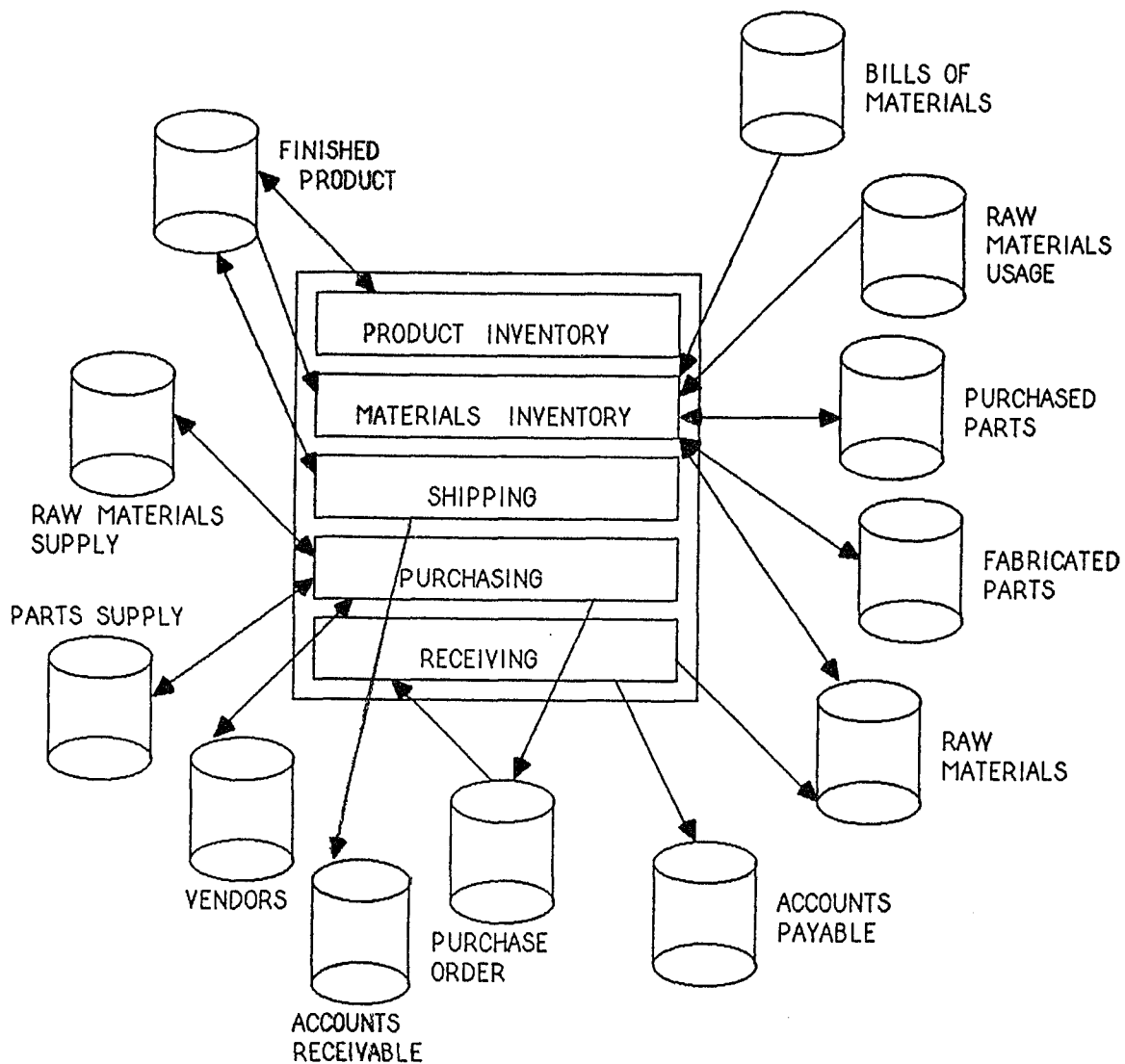
Figure 5.2:   Inventory Function in MOSES

5.2.1   Material Stocks

There are basically four different types of inventory materials:

1.   finished product inventory,

2.   fabricated component parts inventory,

3.   purchased component parts inventory, and

4. raw materials inventory.

Finished products are sold to customers. A finished product may be made up of two different types of components, namely fabricated component parts and purchased component parts. Purchased component parts are purchased directly from vendors. They can be subassemblies or purchased components, such as nuts and bolts. Fabricated components are manufactured within the manufacturing organization. They use raw materials which are bought from vendors in raw form, such as aluminum tubing, plastics resin, etc.

The bills of material and the raw materials usage file establish the relationship between all the materials used in the organization. For example, the finished product bills of material contain all the part numbers, whether the part is purchased or fabricated, and the quantity required of that part per unit of finished product. MOSES users can set the stock levels of all types of material.

5.2.1 Purchasing

The cliche regarding purchasing is that it is responsible for procuring the right materials of the right quality in the right quantity at the right time and at the right price. Cliche or not, without materials, it is impossible to carry out the manufacturing activity.

MOSES views purchasing as a function which closely maps

the production scheduling process. The aim of inventory is to have enough material in stock to supply the production process during the present production period. The aim of purchasing is to supply the proper mix of materials by the time the next production scheduling activity takes place. The MOSES purchasing system computes the demand for each material and component based on the forecasted demand for the finished products in the next scheduling period. Then, after reviewing each material inventory level, MOSES places orders for the materials needed with the goal of acquiring the material before the next scheduling event takes place.

The MOSES user (in Purchasing) has the option of ordering materials based on "economic order quantity" considerations or by overriding the computed order quantity and specifying a different figure based on his own knowledge or intuition. The user can add new vendors to the database or delete existing ones as he establishes new sources of supply or discards old ones. The user can also establish new prices and new delivery dates for particular parts and materials and individual vendors.

5.2.2 Shipping

The shipping function involves collecting all the filled orders and planning the delivery of the finished products to the customer. Shipping is also responsible for invoicing the would ship all filled orders immediately. Conceptually,

shipping sends out finished products after aggregating the quantities to be shipped and making sure that the quantities shipped for each product are greater than some minimum load amount and less than some maximum load amount. If a filled order cannot be shipped during a particular working day, the order is carried forward to the next day.

Shipping parameters (i.e., minimum and maximum load amounts) are specified individually for each product and are stored in the product database file.

5.2.3 Receiving

Receiving is the function which is responsible for receiving and stocking raw materials and purchased component parts. Materials are received on their specified expected receipt dates. In most instances, the arrival of materials on a specific purchase order is to some degree a random process. There is usually an approximate delivery date. Materials may be late, on-time, or early. The delivery period for a pur-chase order has been assumed to be a normally distributed random variable.

Material receiving involves inspection of purchased materials against specifications. Various policies can be adopted with regard to inspection. Every item in some lots may be inspected, while other lots may be only spot-checked. In any case the effect of inspection results in rejecting

some of the received materials. The MOSES user can specify this rate of rejection.

5.3   PRODUCTION FUNCTION

The production function is central to the manufacturing organization. It is here that the raw materials and purchased materials are transformed to finished products using the organization's resources (i.e., men, machines, and materials). The main managerial component of the production function is production planning and scheduling. Figure 5.3 presents the production function and associated databases. All the assumptions which have been made in conceptualizing this function are included in Appendix D. The sections within the MOSES production function are described in the following paragraphs.

5.3.1   Production Parameters

Production parameters describe the production process. The parameters included are such things as the production rates for individual products, the production priority, and the probability of hourly production down time.

5.3.1.1   Production Priority

Production priority refers to the rules for allocating limited resources to different entities. For example, as it is used in MOSES, priority is set by the MOSES user to
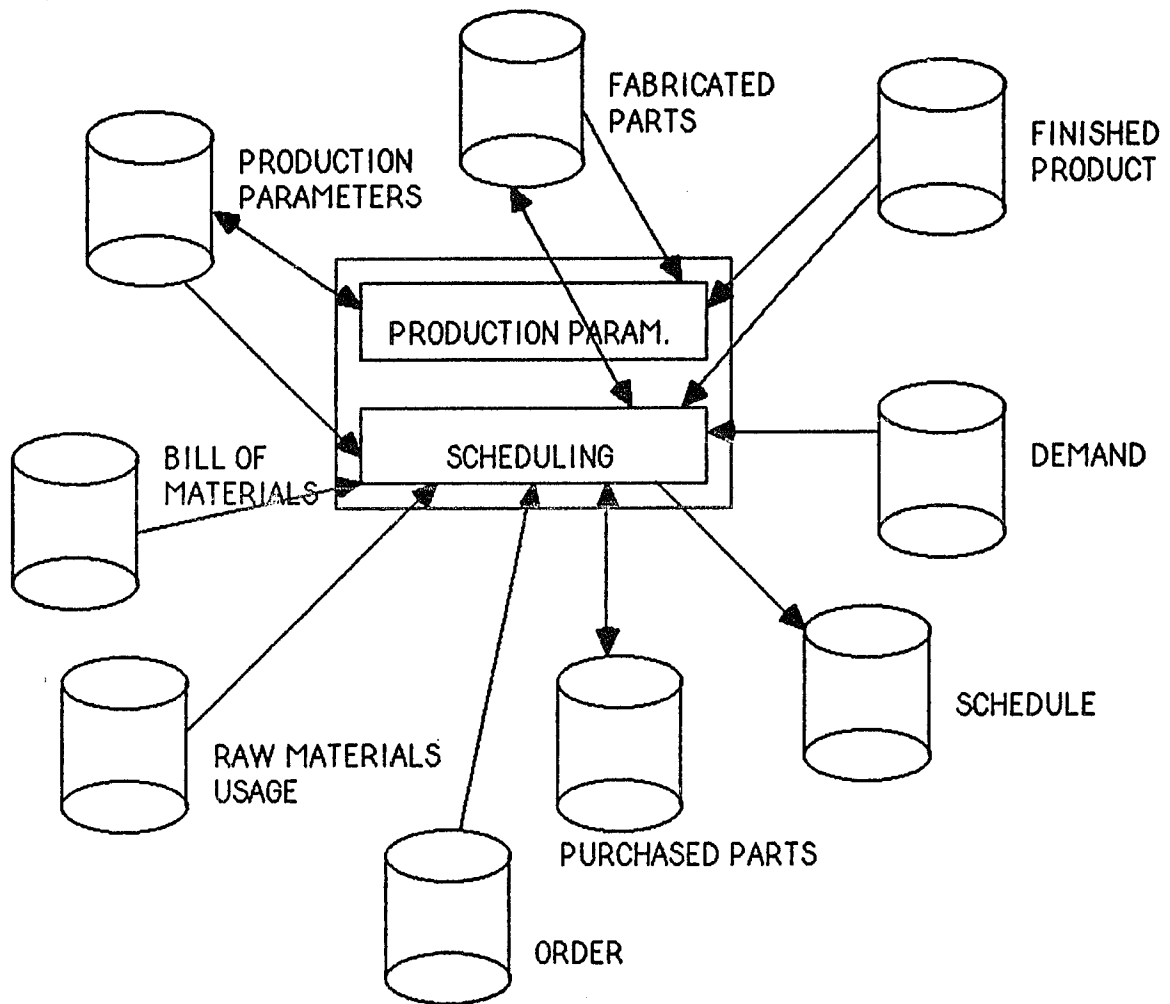
Figure 5.3: Production Function in MOSES

decide which product will be planned or scheduled for production. If the same resources are required by several products and the resources are limited, a higher priority means that a product will be considered for scheduling before the other products. Of course, if resources are sufficient for all the products competing for the same resources, there is no problem. When resources are plentiful, the user has the option of producing more or less of a

desired product. As a default, the scheduling priorities
for all the products and fabricated component parts are
equal.

5.3.1.2 Production Rate

The production rate represents the manufacturing facility's
hourly production capacity for that particular product or
part. There are two parameter values, maximum and minimum
production rates. The idea is that while the hourly produc-
tion rates cannot be greater than some number – no matter
how many products are needed, there is also a minimum pro-
duction rate below which it makes no sense costwise to
produce any products at all.

The present scheduling algorithm schedules production of
particular items based on the production plan quantities,
but always between the maximum and minimum rates. Both
maximum and minimum rates are adjustable by the user and
reflect the user's ability to change the production capacity
as better equipment or processes are added.

5.3.1.3 Quality Control

As it is incorporated within MOSES, quality control repre-
sents the process of inspection. Its function is to deter-
mine whether or not the product or part produced meets the
design specifications. In MOSES, the concept of quality
control is applied by specifying a mean percentage of pro-

ducts or fabricated parts which are rejected because they do not meet specifications. Reject amounts fpr individual products are determined by sampling from a normal distribution with the specified mean. As such, the MOSES user may also specify an associated standard deviation. Of course, if perfect products are produced, both the mean and standard deviation values are set to zero.

5.3.1.4 Production Downtime

Machines, assembly lines, and conveyor belts are subject to breakdown. In MOSES, this failure or non-failure process is assumed to be random. Via a set of probability parameters, MOSES users can specify the frequency of this type of failure. In the current version of MOSES, the user can specify the probabilities of downtimes of 0 minutes, 30 minutes and 1 hour per hour of production operation, with the sum of probabilities equaling one.

5.3.2 Scheduling

Probably the main managerial function performed by production managers is the process of scheduling production according to the production plan, which is based on the marketing forecast. MOSES performs several steps in setting up the production schedule.

5.3.2.1 Aggregate Demand Plan

The demand for individual products is established by market-
ing in the form of a product-by-product forecast. The fore-
cast demands for individual products are increased by cons-
idering product backorders and any quantities of products or
fabricated parts desired by the inventory controller at the
end of the production period. The last quantity mentioned
represents the production concept of build-to-stock. If the
MOSES user wants to operate in response to orders only then
this quantity can be set to zero. Thus, the sum of these
three quantities yields an aggregate demand plan which is
further increased in consideration of the expected scrap
rate for each production item. This then provides the amount
the production function is expected to schedule and produce
during the next production period.

5.3.2.2 Material Requirements

The production scheduling process first compares individual
material availabilities to the aggregate planned production
quantities. The checking is done with respect to currently
available materials in stock. No currently-on-order mater-
ials are considered. Materials are allocated to products and
component parts according to their individual production
priorities. Material shortages are recorded for later pre-
sentation in a Shortage Report. Of course, levels of
individual materials and purchased parts available limit the

numbers of actual finished products and fabricated parts that can be produced in the coming production period.

5.3.2.3 Capacity Requirements

After checking for the availability of individual materials, the production scheduling algorithm next compares the requested production level against the product's available production capacity in terms of its upper and lower limits. The MOSES production scheduler then schedules the planned production quantities, provided that the quantities are within the production limits. Given that the production capacity is adequate, the production scheduler spreads the total production quantities uniformly over the entire production period. If the production capacity is inadequate (i.e., production plan is greater than production capacity), the algorithm schedules production to the maximum allowable level and reports the production capacity deficiency on the Shortage Report.

Once production has been scheduled, the MOSES production function "produces" the finished products and fabricated parts and reports its status to various databases.

5.4 ACCOUNTING FUNCTION

The accounting function is really a simplification of all the financial functions present within an organization. In reality, the "financial function" includes finance, as well

as accounting. The initial version of MOSES, however, includes only the accounting function. Considerations regarding such items as investment alternatives and interest rates are not included. This simplification is necessary because of the complexity involved in financial decisions and because of their tendency to be influenced by the dynamic business climate (e.g., prime lending rate, stock market swings). On the other hand, the accounting aspects which have been included are logical and directly related to the manufacturing organization. For example, increased sales lead to increased revenues and high inventories lead to high costs. As such, the accounting functions included provide opportunities for managers to interject meaningful money-related decisions into the overall process. Figure 5.4 presents the accounting function and associated databases. All the assumptions which have been made in conceptualizing this function are included in Appendix E.

5.4.1 Cost Control

This cost control function provides an opportunity for the user to supply various costs related to functions within MOSES. The costs include production-related costs (such as labor costs, including overtime costs), maintenance-related costs (such as production repair costs), and sales-related costs (such as advertising costs).
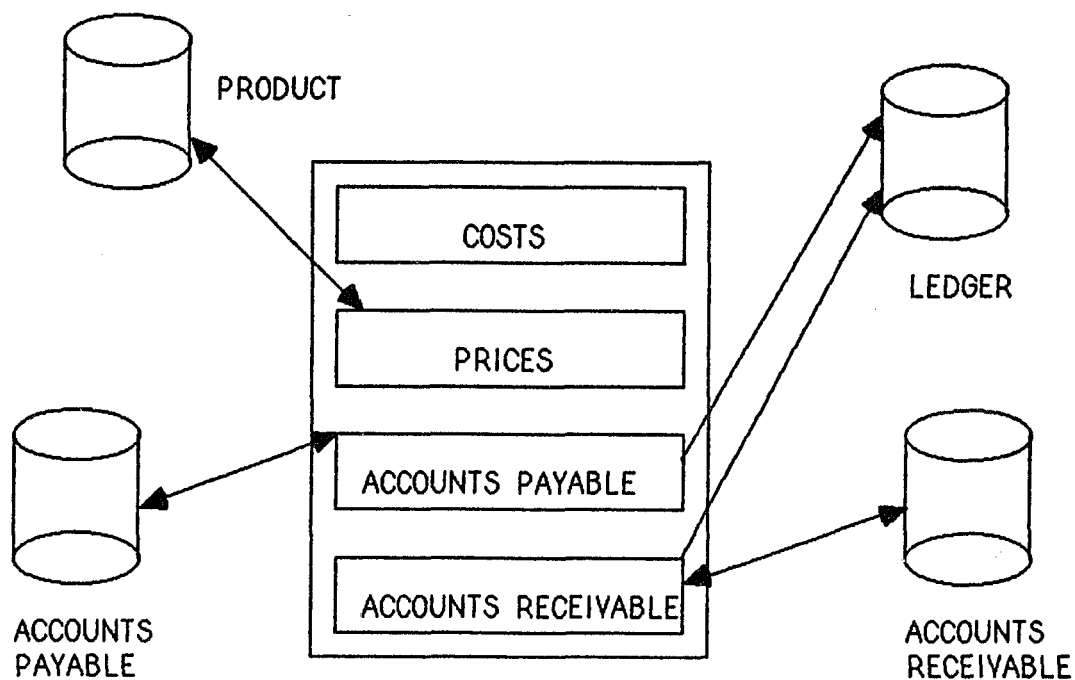
Figure 5.4: Accounting Function in MOSES

5.4.2 Pricing

Through this function, changes to individual finished pro-
duct prices can be made. Also, modification to each pro-
duct's ordering patterns may be carried out. The specifica-
tion of a product's order policy is done in the form of a
distribution and the accompanying parameter values. For
example, suppose that orders for product number 1 are said
to follow a uniform distribution. The MOSES user would first

select the uniform distribution option and would then supply the upper and lower bounds for the distribution in terms of time between orders. During the simulation, the effect of various order pricing policies and order arrival patterns on the organizational cash flow can then be observed.

5.4.3 Accounts Payable

Accounts payable represents the indebtedness of an organization to its creditors, primarily suppliers in this case. How soon an organization pays its bills makes a difference in its cash flow. In the business world, there is a norm of paying bills within 30 days. That is, vendors typically expect payment within 30 days. Organizations naturally prefer to hold on to its money as long possible. The MOSES user can only specify the length of the payment period, not whether or not payment will be made. But, by changing the length of the payment period the MOSES user can observe the effect on the organizational cash flow.

5.4.4 Accounts Receivable

Accounts receivable represents the amount an organization's customers owe to the organization. As was implied in the above discussion regarding accounts payable, the frequency of the receipt of payments is random following some distribution. MOSES assumes that payments from customers are received according to a normal distribution. As such, the

MOSES user may specify the distribution's mean and standard
deviation.

Chapter VI

MOSES: PHYSICAL DESIGN

MOSES has been transformed from concept to reality by physically implementing the ideas on a computer system. Successful implementation begins with the appropriate selection of computer hardware and software systems coupled with an effective software design process.

MOSES is a highly portable software system which will run on any IBM PC XT/AT or clone. MOSES users can effectively work with the model without having any computer-related skills except an ability to use the computer keyboard. The design of MOSES takes advantage of the inherently interactive nature of microcomputers, providing a completely menu-driven interface for users. Through this interface, students, researchers, practitioners, and decision-makers interested in manufacturing systems can build and work with a simulated manufacturing organization without having any knowledge of computer programming or any skill in simulation model building.

MOSES has been designed for ease of use, which is especially important in view of its potential users. This chapter describes the physical design of MOSES in terms of hardware, software, and user interface.

6.1 PROGRAM DESIGN

It is a well-known fact that "inspecting quality into a product" is not possible. While inspection is essential, the only place that product quality can be created is during the production process. The same is true of computer programs. Testing and debugging are inefficient, after-the-fact, and uncertain processes which cannot substitute for writing a program correctly in the first place. Dijkstra [66] clearly showed that, in general, it is impossible within a finite span of time to test every possible case and, hence, that "program testing can be used to show the presence of bugs, but never to show their absence."

6.1.1 Structured Programming

With the above aspects of computer programming in mind, it makes good sense to adopt proven programming techniques from the project's beginning to make program development easier, more nearly free from errors, and easily testable. In the design of MOSES, the concepts of structured programming were used throughout to make the program logic clearly visible and closely related to the conceptual structure of the manufacturing system model.

The following important points suggested by Hill [67] were kept in view while developing MOSES:

> 1. No tricks or "clever" programming using any com-
>   plicated constructs were employed.

2. No meaningless jumps were used (i.e., to avoid "logical spaghetti" that arises from thoughtless jumping around).

3. The if-then-else construct was frequently used. This direct program structure helps to keep the flow of control simple and clear without any possibility of a jump into the structure from anywhere else.

4. Only simple loop structures were employed.

5. In a lengthy program like MOSES (approximately 500 K bytes), even the judicious use of if-then-else and simple loop constructs could result in a program that is unreadable and incomprehensible. Such a situation was effectively avoided by logically dividing the program into a series of modules or procedures (subroutines and functions) designed such that each does a clearly defined task, as far as possible using only its own locally defined variables.

6. Meaningful identifiers were used as variable names. This makes the program to a significant degree self-documenting, so that subsequent program modification is easier because of the degree of understanding provided within the code.

6.1.2 User Interaction

A high quality user interface is one of the strengths of MOSES, a crucial component because of its intended use as an interactive analysis and learning tool for a variety of user-types. It has a simple, logical, color-coordinated user interface which simplifies use of the model. It has both horizontal (LOTUS 1-2-3 like) and vertical (Macintosh like) menus which are extremely easy to use. The programming languages used to develop the user interfaces (dBASE III PLUS [68,69] and Turbo Pascal [70]) are totally transparent

to the user.

MOSES represents a "spreadsheet approach" to manufacturing modeling and simulation. The beauty of using a spreadsheet is that changes to parameter values are immediately reflected in related parts of the spreadsheet. MOSES possesses similar capabilities, although it is not a spreadsheet.

MOSES reduces the typical user-modeling effort by several orders of magnitude, allowing non-programmers to model the manufacturing system of any manufacturing organization. As was the case with spreadsheet software packages, such as LOTUS 1-2-3, this simplified approach to building a manufacturing model is expected to result in a large number of people interested in using the tool.

User-friendly is probably the most overworked of all the terms applied to computing activities. It is a desired virtue which people generally think they understand, but one that is difficult to define in practice. Users of computer programs are often only able to offer a qualitative judgement about a program's "friendliness," by either liking it or not. While human factors researchers are currently addressing this situation, the variety of situations is such that there are no ironclad rules for writing easy-to-use software. As such, it is an evolving art. A great deal of effort has been put into MOSES to make it attractive, functional, logical, and easy to use.

Ideally, a user's manual would be unnecessary. That is, in the best case, all the information that a user needs to use a particular piece of software should be implied, clearly shown, or contained within the program. For an interactive program, this implies the need for an on-screen "help" facility capable of providing the user with readily accessible information about the range of possible actions, what is expected of him, what his options are, and what results he can expect from the selection of a particular option.

Of course, different situations require different levels of assistance. As such an interactive program should possess at least two "help" levels: (1) on-screen help and (2) quickly retrievable help. On-screen help should show important keys and their functions. For example, ↵ might mean "select" or "select the option specified by the cursor's position." This does not mean that every useable key must be described, but that there are frequent occasions in which certain keys should be defined. On-screen help messages should be easily distinguishable from other on-screen information and should be accompanied by simple, one or two word explanations. Quickly-retrievable helps should be readily available on request, immediately viewable on the user's screen when called for, but should not force their way into the user's attention field unless requested. Help messages of this type should provide more detailed information about

a particular option or particular section of a program. MOSES includes both types of user assistance, with important keys clearly labeled near the bottom of the screen. The more extensive quickly-retrievable helps are both functional and attractive and are described in detail later in this chapter.

MOSES is a completely menu-driven, self-contained program. Unlike many simulation models, no special subroutines or procedures need to be added before MOSES is executed. The process of describing a specific manufacturing organization does, of course, require some input. However, the input process is completely interactive, has simultaneous error checking and provides an opportunity for users to instantaneously correct their input errors.

6.2 CHOICE OF HARDWARE

Choosing the appropriate hardware on which to implement MOSES was an instructive exercise, a sort of mini-project in itself. The search for "the right hardware" started at the mainframe computer system level, namely with LSU's IBM system/370. A prototype system development effort using FORTRAN 77 in conjunction with ORACLE (a popular database software package) on the IBM VM system proved to be an inappropriate choice. (Note: The LSU MVS system was ruled out because of its batch orientation.) Although powerful computationally, the LSU VM system environment had several

disadvantages some of which were severe: (1) lack of rapid system responsiveness (due to frequent equipment overload and distance/network-type criteria), (2) lack of general-access color terminals, (3) lack of portability, (4) cumbersome "bootstrap" process (when compared to a microcomputer), and (5) lack of full-compliment of DBMS modules (screen generation software was not yet available).

The primary disadvantage for this project among those listed was the system's lack of responsiveness. While the LSU VM system is intended to be an interactive computer system, in actuality it is not (at least not sufficiently interactive for a program like MOSES). It was also thought that a microcomputer-based system would have a potentially broader user base.

The next logical option was to consider possible microcomputer systems. Microcomputers are available as stand-alone, desktop, and lap-top systems and can be linked to other microcomputers or mainframe systems through appropriate communication interfaces. Microcomputers have made remarkable progress in a single decade. Early microcomputers lacked the speed, memory capacity, and on-line auxiliary storage capacity for a project such as this one. But the situation has changed, such that 16-bit microcomputers are widely used and the newer 32-bit microcomputers are readily available.

Along with the developments in hardware capabilities of

microcomputers, there have been major advances in micro-computer software capabilities as well. Operating system software, such as MS-DOS, has become nearly standardized and almost all the current high-level languages, including FORTRAN 77, PASCAL, C, LISP, PROLOG, ADA, and so forth, are generally available on microcomputers. Also, powerful micro-based application development software, such as the dBASE series, LOTUS 1-2-3, and Word Perfect, is universally accep-ted and widely used.

MOSES was developed to run under MS-DOS on an IBM PC XT/AT or any of the numerous compatibles. Since their arri-val on the market in August, 1981, IBM personal computers have become commonly used in business. In fact, their popu-larity has prompted hundreds of other computer manufacturers to bring out special-purpose systems which are compatible with and which somehow enhances the software developed on IBM personal computers. Over time, hardware such as this will facilitate the use of MOSES and will aid in further refinements of the software. A list of MOSES' hardware requirements is presented in Table 6.1. Table 6.2 summarizes some of the important hardware characteristics of an IBM PC AT.

6.3   CHOICE OF SOFTWARE

At one time, software choices were limited to a handful of general-purpose languages. Fortunately, those days are gone.

Operating System:	MS-DOS/PC-DOS 3.1 or later
Main Memory:	512 K Bytes
Auxilliary Storage: (dBASE III PLUS)	774 K Bytes
Auxilliary Storage: (MOSES)	500 K Bytes
Hardware System:	IBM PC XT/AT or clones with at least 512K Bytes RAM memory and at least a 10 M Bytes hard disk with a color monitor (optional)

Table 6.1: MOSES' Hardware Requirements

However, today's software has a variety of characteristics. As such, the choice of software has a profound effect on some of the above-mentioned characteristics considered desirable in a computer program. MOSES was developed using two of the most popular software packages available for use on microcomputer systems. The simulation model, the input and output screens, and all computations were programmed using the database management application development software known as dBASE III PLUS from Ashton-Tate. The extensive module menus were developed using the high-level language known as Pascal (sold under the trade name of Turbo Pascal by Borland, Inc.).

dBASE III PLUS is a flexible database management software package which has several attractive features (e.g., a

```
----------------------------------------------------------------

          Processor:              Intel 80286

          Processor Speed:        8 Mega hertz

          Main Memory:            640 K Bytes

          Auxilliary Storage:     20 M Bytes

          Peripherals:            One Parallel Port
                                  One RS-232 Serial Port


          Table 6.2:   Characteristics of IBM PC AT

----------------------------------------------------------------
```

database structure may be easily redefined) which makes it an appropriate choice for both database applications and for simulation modeling. As was described in previous chapters, one of the important characteristics of MOSES is its integration of database concepts with simulation modeling techniques. dBASE III PLUS provides facilities for easily creating, maintaining, and manipulating databases, as well as providing a structured, high-level programming language. Data definition and data manipulation commands, such as CREATE database, UPDATE database, DISPLAY database, and LOCATE a record in the database, are embedded within the constructs of the high-level language.

The dBASE III PLUS programming language possesses many of the structured programming characteristics which allow the programmer to follow the previously-mentioned criteria for good program design. dBASE III PLUS has a relatively small

number of constructs, but the language is quite powerful because these constructs can be combined in many ways. Programs written in dBASE III PLUS are easy to read and understand. Without exception, the logic contained in the language control structures is easy to verify. Modular program development is readily accomplished in dBASE III PLUS, an advantage which will simplify future MOSES modifications and enhancements. In addition to the above advantages, dBASE III PLUS programs are easily debugged since the language executes in interpretative mode and provides useful debugging features, such as an interactive debugging device.

As stated above, the MOSES interactive menus were developed using Turbo Pascal. The menu-generation program created is a general-purpose software subsystem which accepts menu names as data and creates a menu of the form used throughout MOSES. Turbo Pascal also includes structured programming constructs which allows modular, easy-to-follow program development. MOSES' software specifications are shown in Table 6.3.

6.4 MENU-DRIVEN INPUT/OUTPUT

As mentioned previously, one of the most important features of MOSES is that it is completely menu-driven. Menus are generated by a program written in Turbo Pascal. The options selected are returned to the calling programs written in dBASE III PLUS. Figures 6.1, 6.2, and 6.3 are typical exam-

---

Simulation Approach:	Interactive (batch processing allowed)
Access to Model:	Menu-Driven; horizontal and vertical menus
Number of Program Modules:	170
Number of Database Files:	13
Operating System:	MS-DOS/PC-DOS 3.1 or later
Languages Used:	dBASE III PLUS version 1.1 Turbo Pascal version 3.1

Table 6.3:   MOSES' Software Specifications

---

ples of menu screens used throughout this menu-driven program.

Note that there are only a few keys which respond to the options.   The definitions of these keys are always displayed on the screen.   Note also that more extensive help is available.

6.5   INTERACTIVE SCREENS

Users work with MOSES through a series of interactive screens.   These screens are used to provide the user on-line help, opportunities to view, change, and print the model input and the capability of viewing and printing the model output.

```
┌──────────────────────◄MAIN MOSES MENU►──────────────────────┐
│                                                              │
│   Example        Existing        Add       Delete      Quit  │
│                                                              │
├──────────────────────────────────────────────────────────── ┘
        ┌─────────────◄Existing►─────────────┐
        │                                    │
        │ ABC Pencil Co., Shreveport, LA     │
        │ XYZ Penmanship, Inc., Baton Rouge, LA│
        │                                    │
        │         Option 1  of 2             │
        │                                    │
        └────────────────────────────────────┘



   ┌────────────────────◄EXPLANATION►─────────────────────────┐
   │ Work with a Previously Defined Manufacturing Organization │
   │ Select ABC Pencil Co., Shreveport, LA                     │
   │──────────────────────────────────────────────────────────│
   │   Help         Horizontal        Vertical       Select    │
   │   (F1)            ↔                 ↑↓             ↵       │
   └──────────────────────────────────────────────────────────┘
```
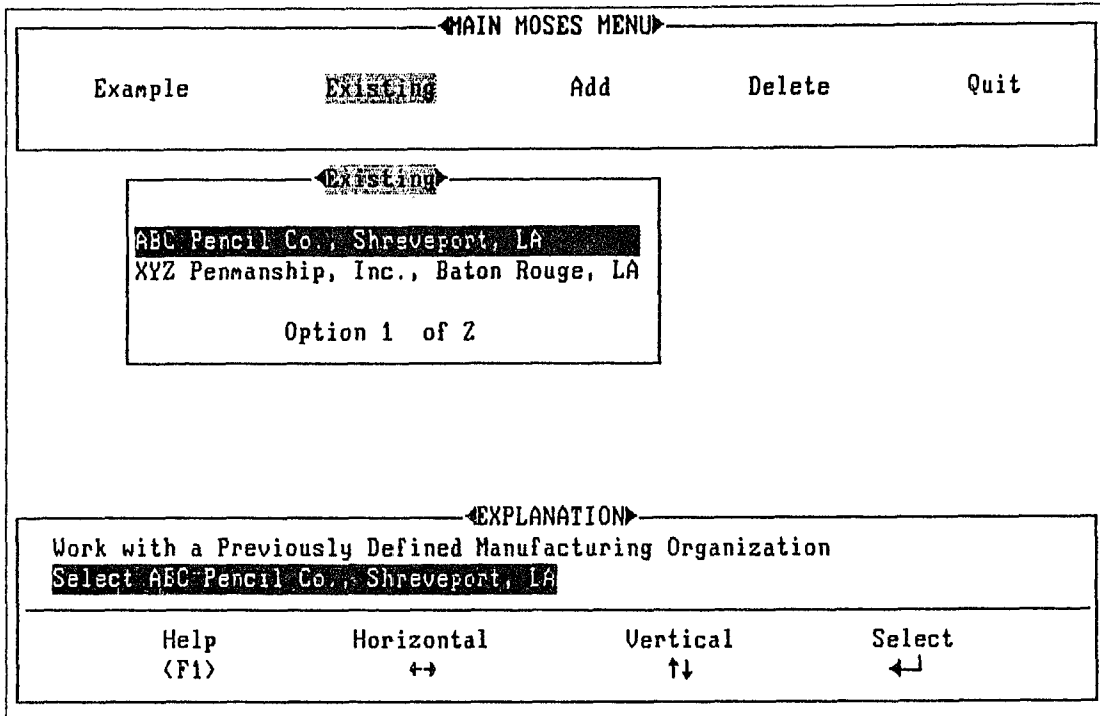
Figure 6.1:   Main MOSES Menu

```
┌─────────────────◄MANUFACTURING MODEL MENU►───────────────────┐
│                                                              │
│  Global      Background     Input     Go    Output    Quit   │
│                                                              │
      ┌──────────────◄Background►──────────────┐
      │                                        │
      │ Inventory List, Finished Product       │
      │ Inventory List, Fabricated Parts       │
      │ Inventory List, Purchased Parts        │
      │ Inventory List, Raw Materials          │
      │ Bills of Material, Single-Level        │
      │                                        │
      │         Option 5  of 15                │
      └────────────────────────────────────────┘

   ┌────────────────────◄EXPLANATION►─────────────────────────┐
   │ Display Background Information for the Selected Organizational Model │
   │ View and/or print single-level bills of material (for all products) │
   │──────────────────────────────────────────────────────────│
   │   Help         Horizontal        Vertical       Select    │
   │   (F1)            ↔                 ↑↓             ↵       │
   └──────────────────────────────────────────────────────────┘
```

Figure 6.2:   Manufacturing Model Menu

```
┌──────────────────────────────◄INVENTORY MENU►──────────────────────────────┐
│ ┌─────────────────────────────────────────────────────────────────────────┐ │
│ │  Product    Shipping    Materials    ▓Purchasing▓   Receiving   Quit     │ │
│ │                                                                          │ │
│ └─────────────────────────────────────────────────────────────────────────┘ │
│                          ┌───────────────◄Purchasing►──────────────┐         │
│                          │  Fab Parts Shortage List, View           │         │
│                          │  ▓Raw Materials Purchasing, Change▓       │         │
│                          │  Raw Materials Vendors, Change            │         │
│                          │  Raw Materials Vendors, View              │         │
│                          │  Component Parts Purchasing, Change       │         │
│                          │                                           │         │
│                          │            Option 4  of 9                 │         │
│                          └───────────────────────────────────────────┘         │
│ ┌──────────────────────────────◄EXPLANATION►─────────────────────────────┐  │
│ │ Set Materials Purchasing Parameter Values                               │  │
│ │ ▓Set raw materials inventory parameter values▓                          │  │
│ │ ───────────────────────────────────────────────────────────────────────│  │
│ │     Help            Horizontal          Vertical          Select        │  │
│ │     <F1>               ↔                   ↑↓               ↵            │  │
│ └─────────────────────────────────────────────────────────────────────────┘ │
└─────────────────────────────────────────────────────────────────────────────┘
```

Figure 6.3:   Inventory Menu

6.5.1   Help Screens

On menus which indicate the availability of function key
<F1>, more extensive on-line help is available. This level
of assistance, referred to earlier as quickly-retrievable
help, is initially stored on disk. However, the help screens
are buffered and stored in main memory during their display.
This means that once their content is stored in memory, it
is instantly retrievable. This program structure allows the
on-line helps to be quickly available on request. Help
screens can be composed of one, two, three, or four pages.
Although only one page at a time can be read, parts of all
the screens can be displayed simultaneously. This alerts the

user to the availability of additional help. Figures 6.4, 6.5, and 6.6 show help screens in the multi-page format. Users can "turn the pages" back and forth by using dedicated keys whose definitions displayed on the screen.

6.5.2 View Screens

View screens are used for viewing and possibly printing the various model parameter values shown. They are used to display both input parameter values and simulation output results.

In a manner similar to the help screens, they are buffered so that up to four screens of data can be stored in main memory simultaneously. Storing consecutive data-filled

```
==◄MANUFACTURING MODEL►====
                                                     Date: 04/21/88
          ◄Raw Materials Inventory►
            ◄Fabricated Parts Inventory►
              ◄Purchased Parts Inventory►
                ◄Finished Product Inventory►

        Finished Product Inventory includes the entire product line
        produced by the manufacturing organization. For each product,
        the product number, product description, selling price, cur-
        rent number in stock, and desired end-of-production period
        stock level values are shown.

        The values can only be viewed in the BACKGROUND section, but
        can be changed through the INPUT section of the MANUFACTURING
        MODEL MENU.



               〈PgUp〉 - next                〈Q〉 - quit
```

Figure 6.4: Multi-page Format Help Screen

```
╔══════════════════════════════════════════════════════════════╗
║ ╔════════════════════◀MANUFACTURING MODEL▶══════════════════╗ ║
║ ║                                              Date: 04/21/88 ║ ║
║ ║    ┌──────────────◀Raw Materials Inventory▶──────────┐     ║ ║
║ ║    │                                                 │     ║ ║
║ ║    │   ┌──────────◀Fabricated Parts Inventory▶────────┐    ║ ║
║ ║    │   │                                              │    ║ ║
║ ║    │   │  ┌────────◀Purchased Parts Inventory▶───────────┐ ║ ║
║ ║    │   │  │                                              │ ║ ║
║ ║    │   │  │ The Purchased Parts Inventory includes the names, numbers, │
║ ║    │   │  │ and other values for all of the organization's purchased   │
║ ║    │   │  │ parts.  The order cost and annual carrying cost per unit val- │
║ ║    │   │  │ ues are included in the file along with the current number in │
║ ║    │   │  │ stock, average daily demand for the part, the quantity cur- │
║ ║    │   │  │ rently on order, and the reorder quantity.   │ ║ ║
║ ║    │   │  │                                              │ ║ ║
║ ║    │   │  │ The values can only be viewed in the BACKGROUND section, but │
║ ║    │   │  │ can be changed through the INPUT section of the MANUFACTURING │
║ ║    │   │  │ MODEL MENU.                                  │ ║ ║
║ ║    └   │  │                                              │ ║ ║
║ ║        └  │    <PgUp> - next     <PgDn> - previous     <Q> - quit │
║ ║           │                                              │ ║ ║
║ ║           └──────────────────────────────────────────────┘ ║ ║
║ ╚════════════════════════════════════════════════════════════╝ ║
╚══════════════════════════════════════════════════════════════════╝
```

Figure 6.5:   Help Screen Showing the Second Page

```
╔══════════════════════════════════════════════════════════════╗
║ ╔════════════════════◀MANUFACTURING MODEL▶══════════════════╗ ║
║ ║                                              Date: 04/21/88 ║ ║
║ ║    ┌──────────────◀Raw Materials Inventory▶──────────┐     ║ ║
║ ║    │                                                 │     ║ ║
║ ║    │   ┌──────────◀Fabricated Parts Inventory▶────────┐    ║ ║
║ ║    │   │                                              │    ║ ║
║ ║    │   │ Fabricated parts are products manufactured within the organi- │
║ ║    │   │ zation's facilities which are used in finished products (such │
║ ║    │   │ as the ballpoint writing assembly used in a ballpoint pen). │
║ ║    │   │ The Fabricated Components Part Inventory file includes the │
║ ║    │   │ daily demand, the annual per unit carrying cost of each fab │
║ ║    │   │ part, and the in stock, in process, and desired inventory │
║ ║    │   │ levels for each fabricated part.              │    ║ ║
║ ║    │   │                                              │    ║ ║
║ ║    │   │ The values can only be viewed in the BACKGROUND section, but │
║ ║    │   │ can be changed through the INPUT section of the MANUFACTURING │
║ ║    │   │ MODEL MENU.                                  │    ║ ║
║ ║    └   │                                              │    ║ ║
║ ║        │    <PgUp> - next     <PgDn> - previous     <Q> - quit │
║ ║        └──────────────────────────────────────────────┘    ║ ║
║ ║                                                            ║ ║
║ ╚════════════════════════════════════════════════════════════╝ ║
╚══════════════════════════════════════════════════════════════════╝
```

Figure 6.6:   Help Screen Showing the Third Page

screens in memory makes the process of screen recall extremely efficient. A single key stroke will cause MOSES to print a report consisting of the parameter values being viewed on the screen. Figures 6.7 and 6.8 show examples of MOSES view screens. Notice that the key definitions at the bottom of the screen always display the range of possible user options.

6.5.3 Change Screens

Change screens are used in MOSES to provide the user with opportunities to change the parameter values. These screens are designed and function in a manner that is similar to view screens described above, but change screens also allow

```
╔══════════════════════════◄MARKETING - FORECAST►══════════════════════════╗
║┌────────────────────────────────────────────────────────────────────────┐║
║│ ABC Pencil Co., Shreveport, LA                          Date: 04/21/88  │║
║│ Page: 2 of 3                                                            │║
║│                   PRODUCT SALES HISTORY AND FORECAST                     │║
║│                     FOR PERIOD 04/21/88 - 04/27/88                       │║
║│                                                                          │║
║│ Period Length of Past Sales Data: 7 days                                 │║
║│ Method of Preparing Forecast:     Moving Average                         │║
║│                                                                          │║
║│                       Total  --Prior Period-- -------Next Period-------  │║
║│ Product    Product     Data  Sales   Sales    Sales  R.M.S.   Moving     │║
║│ Number   Description  Periods Actual Forecast Forecast Error  Periods    │║
║│                                                                          │║
║│    4   Ball Point Pen Type 11  4333   3444   * 5000   935.62     1       │║
║│                                                                          │║
║│    5   Fountain Pen Type B  7  3556   2367     3556  1004.16     1       │║
║│                                                                          │║
║│    6   Mechanical Pencil Ty 8  4222   5222   * 3000   909.86     1       │║
║│                                                                          │║
║│ * Quantity Modified by the Manager                       Continued...    │║
║│──────────────────────────────────────────────────────────────────────  │║
║│      Prev Page        Next Page        Print          Exit              │║
║│      (PgUp)           (PgDn)             P            (Esc)              │║
║└────────────────────────────────────────────────────────────────────────┘║
╚══════════════════════════════════════════════════════════════════════════╝
```
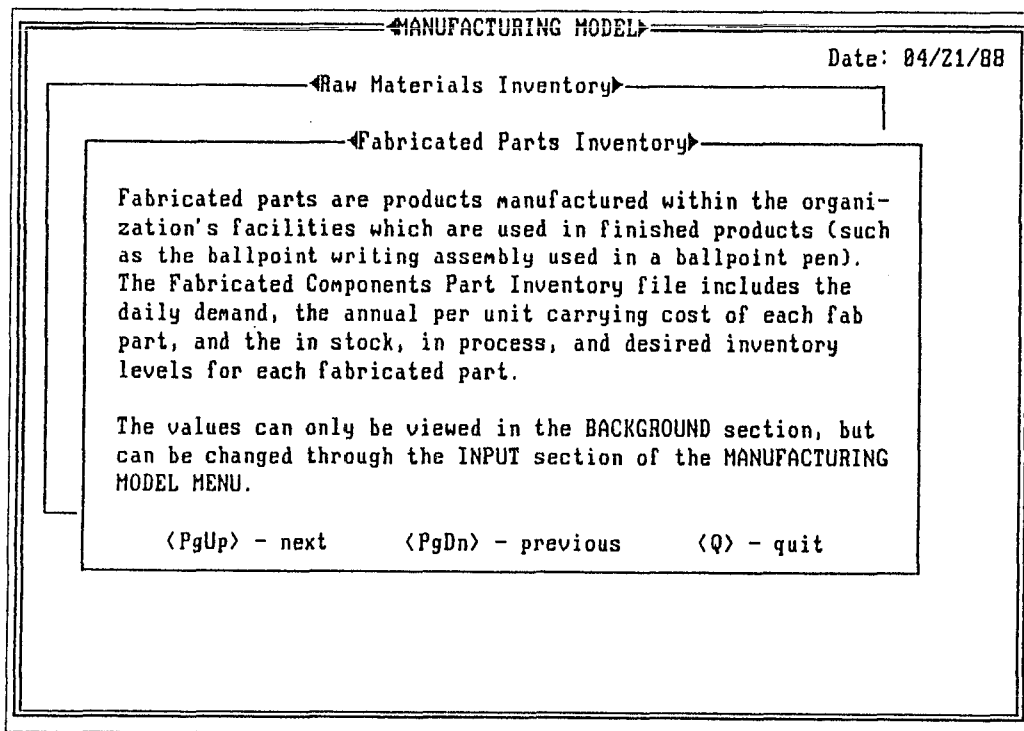
Figure 6.7: View Screen Showing Current Sales Forecast

```
========================◄MANUFACTURING MODEL - BACKGROUND►========================
ABC Pencil Co., Shreveport, LA                              Date: 04/21/88
Page: 3 of 9
                            WHERE-USED BILL OF MATERIALS


   Part      Part       Fabricated/ Product      Product        Qty
   Number    Description Purchased   Number       Description    Used

   1006  SPRING         Purchased       1    Ball Point Pen Type A  1
                                        4    Ball Point Pen Type B  1

   1007  INK CARTRIDGE  Purchased       1    Ball Point Pen Type A  1
                                        4    Ball Point Pen Type B  1
                                        7    Ball Point Pen Type C  1

   1008  BODY           Fabricated      2    Fountain Pen Type A    1

   1009  CAP            Fabricated      2    Fountain Pen Type A    1
                                                            Continued...

          Prev Page        Next Page         Print        Exit
          (PgUp)           (PgDn)            P            (Esc)
```

Figure 6.8:   View Screen Showing Where-Used Bill of Material

the user to make changes in predefined areas of the screen. This is accomplished by moving the cursor to those desired places and then using the standard keyboard editing keys to enter new values.

There are essentially two types of change screens. Type one only allows changes in the predefined fields. No provisions are made to add or delete rows of data shown on the screen. Figure 6.9 provides an example of this type of change screen. The second type of change screen allows both changes in the parameter values as well as providing the capability to add or delete entire rows of data. Figure 6.10 shows an example of this type of change screen.

```
╔═══════════════════════◄MARKETING - MODIFY►═══════════════════╗
║ ABC Pencil Co., Shreveport, LA                    Date: 04/21/88 ║
║ Page: 1 of 2                                                     ║
║                        PRODUCT SALES FORECAST                    ║
║                  FOR THE PERIOD    04/21/88 - 04/27/88           ║
║                                                                  ║
║ Period Length of Past Sales Data: 7 days                        ║
║ (Used in Preparing Forecast)                                    ║
║                                                                  ║
║      Product      Product          Sales Forecast   Sales Forecast ║
║      Number       Description      (Computed)       (Modified)   ║
║                                                                  ║
║         1     Ball Point Pen Type A      3424          ▓▓▓▓▓     ║
║                                                                  ║
║         2     Fountain Pen Type A        2902          ▓▓▓▓▓     ║
║                                                                  ║
║         3     Mechanical Pencil Type A   3245          ▓▓▓▓▓     ║
║                                                                  ║
║         4     Ball Point Pen Type B      4333          ▓▓▓▓▓     ║
║                                                          Continued... ║
║ ──────────────────────────────────────────────────────────────── ║
║    Cursor Movement      Prev Page     Next Page    End Save   Exit ║
║    (Home) ←↑↓→ (End)     (PgUp)        (PgDn)      (Ctrl)W    (Esc) ║
╚══════════════════════════════════════════════════════════════════╝
```

Figure 6.9:   Change Screen Showing Forecast Modification

```
╔══════════════════════◄INVENTORY - PURCHASING►═══════════════════╗
║ ABC Pencil Co., Shreveport, LA                    Date: 04/21/88 ║
║ Page: 3 of 7                                                     ║
║                   PURCHASED COMPONENT PARTS VENDORS              ║
║                                                                  ║
║                                                        Expected  ║
║   Part  Vendor                          Vendor Unit Price Delivery ║
║   Number Number        Vendor Name       Ref  ($/unit) Period(days) ║
║                                                                  ║
║   1012   102   Silver Stick Company      ERF0   0.39       5     ║
║                                                                  ║
║   1012   106   Mississippi Pens, Inc.    WSE3   0.43       4     ║
║                                                                  ║
║   1013   ▓102▓ ▓Silver Stick Company▓    ▓UE2▓  ▓0.45▓    ▓5▓    ║
║                                                                  ║
║   1013   104   Rust Bowl, Inc.           QUE3   0.24       7     ║
║                                                                  ║
║   1013   107   Hot Shot Company          TYE3   0.56       4     ║
║                                                          Continued... ║
║ ──────────────────────────────────────────────────────────────── ║
║   Insert      Delete      Prev Page    Next Page   End Save   Exit ║
║   (F1)     (Ctrl)(Home)    (PgUp)       (PgDn)     (Ctrl)W    (Esc) ║
╚══════════════════════════════════════════════════════════════════╝
```

Figure 6.10:   Change Screen Showing Component Parts Vendors

6.6   PROGRAM MODULES

The design of MOSES is completely modular. Every option on every MOSES menu represents a separate program module. Each program module consists of dBASE III PLUS programming language statements with data definition and data manipulation commands embedded within them. A module may call other modules during its execution. Thus, program nesting is permitted during module execution. (Note: dBASE III PLUS allows nesting up to 16 levels deep.)

Since program modules are stored in computer files and since MS-DOS files can have names only eight characters (or less) in length, a consistent and systematic naming scheme was developed to label the modules so that their functions could be determined easily. Otherwise, with so many modules (approximately 170) it would be extremely difficult to keep track of the code capabilities within individual modules. For example, file names ending in "view" (e.g., prodview.prg) contain the view screen modules. File names ending in "chng" (e.g., prodchng.prg) contain the change screen modules. Similarly, file names starting with "help" (e.g., helpglob.prg) contain the help screen modules.

6.7   PROGRAM DATABASE FILES

Database files are central to the structure of MOSES. They store data which define the structure for individual manufacturing organizations. Database files are also used to

store the intermediate and final results of a simulation run. Thus, there are essentially two types of database files employed in MOSES. The first type of database files contains the parameter which define the organization being modeled. MOSES users do not operate on these files directly. Rather, the files are copied into identically structured working files when a particular model is selected.

The second type of file is used to store intermediate and final results from the simulation. These files are automatically initialized at the beginning of each simulation run and may be initialized during the run, if the user so desires.

6.8 RANDOM SAMPLING FROM DISTRIBUTIONS IN MOSES

Almost all simulation models have components which are stochastic in nature. MOSES is no exception. Therefore, there is a frequent need for the model to make random samples and assign values to probabilistic variables (e.g., time until the next order arrival, order quantity, and production downtime). MOSES includes a pseudo random number generator and allows the user to sample from well-known probability distributions, such as the exponential, normal, and uniform, as well as from user-defined probability distributions. The MOSES design structure makes it possible for users to easily add additional probability distributions in the future.

6.9   VERIFICATION

Verification is concerned with determining whether or not the simulation program is working as intended; that is, whether or not it is debugged. Initial verification efforts have included the following steps:

1. The model was coded and debugged in steps.

2. The interactive debugger was used to check the correctness of each program path.

3. Model results were checked for reasonableness.

4. Model statistics for input probability distributions were compared to tabulated data values.

While these actions do not guarantee a completely verified model, they do represent a serious initial effort. Verification will continue as the model is used and continues to evolve.

6.10   VALIDATION

Validation of such a complex manufacturing organization model, although admittedly important, is extremely difficult to perform. Model validation usually includes an attempt to reproduce during some period of time the performance of the actual system. This approach involves the validator in both full-scale modeling and real-data collection. Thus, in order to conclusively declare that the model has been validated, it is necessary to develop a model containing all the con-

plexities of the real system and to run the model at full-scale to generate realistic output. Since such a complicated development project would probably never be completed, we are right back to square one. Thus, it should be recognized that this objective of proving the simulation correct can only be approached, not achieved [71,72].

The real purpose of a simulation model is to point the users in the right direction. That is, a "valid" simulation model should indicate correctly that if certain levels of changes are made, productivity or profitability will either get better or worse. No one can claim that simulation model results are precise. Nevertheless, simulation models can often be used successfully if they can lead users to the discovery of new insights about the system being modeled and help users foresee the types of results which are likely to occur under a variety of prespecified conditions. In other words, while complex simulation models cannot be completely validated, their thoughtful use over time - coupled with model alteration when appropriate - serves as a reasonable substitute.

Each time MOSES is run, a single set of simulation results is generated. By changing only the random number seed, a different set of simulation results will be created. This means that users have the capability of "playing the same hand" repeatedly and of analyzing and evaluating the changing results. By doing this repeatedly, one gets a sense

of the shape of the response surface of system performance and some idea of how sharp the peaks and precipices are in that surface [44].

Chapter VII

MOSES: IN ACTION

Both the process and the results of a sample MOSES run are presented in this chapter. The purpose of the run is to briefly illustrate the use of MOSES. While demonstrating all of the capabilities of MOSES would require several volumes, this chapter is intended to provide a glimpse at how a MOSES user might interact with the modeling system. (Note: The MOSES User's Guide, which is at this writing in the process of being completed, contains numerous sample runs.)

A hypothetical manufacturing organization, ABC Pencil Company of Shreveport, Louisiana, manufactures seven distinct products. These products are shown in the product list given in Figure 7.1. All seven products are manufactured using two types of parts, fabricated and purchased. Fabricated parts are manufactured within the organization from raw materials purchased from suppliers, while purchased parts are bought from vendors and become part of assembled finished products. A typical bill of materials for product number 3, Mechanical Pencil Type A, is shown in Figure 7.2. A total of 35 different component parts are required to manufacture the seven finished products. Production parameters which specify the details of the ABC Pencil Company's

ABC Pencil Co., Shreveport, LA   Date: 05/01/88
Page: 1
                        PRODUCT INVENTORY LIST

Product Number	Product Description	Selling Price ($/unit)	Carrying Cost ($/unit)	Current Number in Stock	Desired End of Prodn Period Stock
1	Ball Point Pen Type A	5.99	0.10	4	200
2	Fountain Pen Type A	7.99	0.10	20	40
3	Mechanical Pencil Type A	4.95	0.10	42	100
4	Ball Point Pen Type B	10.99	0.10	3	200
5	Fountain Pen Type B	15.00	0.10	19	40
6	Mechanical Pencil Type B	5.95	0.10	16	100
7	Ball Point Pen Type C	12.99	0.10	8	200

Figure 7.1:   Product Inventory List

ABC Pencil Co., Shreveport, LA   Date: 05/01/88
Page: 1
                     SINGLE-LEVEL BILL OF MATERIALS

Product Number: 3
Description: Mechanical Pencil Type A

Part Number	Part Description	Fabricated/Purchased	Quantity
1004	CLIP	Fabricated	1
1015	BODY	Fabricated	1
1016	LEAD CASSETTE	Purchased	1
1017	ERASURE ASSEMBLY	Purchased	1
1018	LEAD GUIDE	Purchased	1
1019	SPRING	Purchased	1
1020	COLLETTE ASSEMBLY	Purchased	1

Figure 7.2:   Bill of Materials

production processes are shown in Figure 7.3 and the projected ordering patterns for each individual product are given in Figure 7.4. Several other parameters are required to completely describe the manufacturing organization for inclusion in MOSES. These parameters are stored in files similar to those described above and include the following: product sales history, backorder policy, information about purchased and fabricated parts, raw materials, vendor information, and production parameters for fabricated parts.

All of the above information is defined and added to MOSES databases through MOSES' interactive model building process. The model building task is managed by a portion of MOSES called the Model Manager, which allows users to define

ABC Pencil Co., Shreveport, LA   Date: 05/01/88
Page: 1
PRODUCTION PLANNING & CONTROL PARAMETERS (PRODUCT)

Length of Production Period: 7 days
Daily Shift Hours: 8 hours

Item Number	Item Description	Prio- rity	Rate (Hourly) Min	Max	Scrap Rate(%) Mean	StDv	Prob. of Hourly Prodn. Down Time 0Min	30Min	1Hr
1	Ball Point Pen	1	26	65	5.00	1.50	0.93	0.05	0.02
2	Fountain Pen Ty	1	33	56	4.50	1.20	0.95	0.02	0.03
3	Mechanical Penc	1	30	50	6.30	1.70	0.92	0.04	0.04
4	Ball Point Pen	1	28	70	5.00	1.20	0.93	0.05	0.02
5	Fountain Pen Ty	1	30	60	4.50	1.80	0.95	0.02	0.03
6	Mechanical Penc	1	30	50	6.30	1.00	0.92	0.04	0.04
7	Ball Point Pen	1	20	45	5.00	1.40	0.93	0.05	0.02

Figure 7.3: Production Planning and Control Parameters

ABC Pencil Co., Shreveport, LA   Date: 05/01/88
Page: 1
                        PRODUCT ORDER PROFILE

Product Number	Product Description	Time Between ---Order Arrivals--- Dist	(Minutes)	----Order Size---- Dist	(Units)
1	Ball Point Pen Type A	UNI	Min = 5.00 Max = 60.00	EXP	Mean = 37
2	Fountain Pen Type A	NOR	Mean = 34.00 StDv = 5.00	UNI	Min = 25 Max = 100
3	Mechanical Pencil Type	UNI	Min = 5.00 Max = 60.00	EXP	Mean = 67
4	Ball Point Pen Type B	EXP	Mean = 27.00	UNI	Min = 5 Max = 60
5	Fountain Pen Type B	EXP	Mean = 46.00	NOR	Mean = 45 StDv = 5.50
6	Mechanical Pencil Type	UNI	Min = 5.00 Max = 60.00	UNI	Min = 25 Max = 100
7	Ball Point Pen Type C	UNI	Min = 10.00 Max = 70.00	EXP	Mean = 40

Figure 7.4:   Product Order Profile

new organizations, delete existing organizations, and select
particular organizations with which to work.

Provided that the above described background   information
has   already   been   entered,   the ABC Pencil Company   may   be
selected for analysis at the model manager level of the Main
MOSES Menu (Figure 7.5).   Once selected, all the information
related   to   this   organization   is copied   from   disk   into
working-area   files.   When the loading process is   complete,
the   user   is presented the MOSES Manufacturing   Model   Menu
(Figure   7.6).   The user has several options from   which   to
choose.   If   the user selects the Go option,   the simulation
will   begin using the parameter values described   previously

```
┌─────────────────────────────◄MAIN MOSES MENU►──────────────────────────────┐
│ ┌─────────────────────────────────────────────────────────────────────────┐ │
│ │                                                                           │ │
│ │    Example         Existing          Add          Delete         Quit     │ │
│ │                                                                           │ │
│ └─────────────────────────────────────────────────────────────────────────┘ │
│       ┌──────────────────◄Existing►──────────────────┐                       │
│       │                                              │                       │
│       │ ABC Pencil Co., Shreveport, LA               │                       │
│       │ XYZ Penmanship, Inc., Baton Rouge, LA        │                       │
│       │                                              │                       │
│       │           Option 1  of 2                     │                       │
│       │                                              │                       │
│       └──────────────────────────────────────────────┘                       │
│                                                                               │
│ ┌─────────────────────────◄EXPLANATION►────────────────────────────────────┐ │
│ │ Work with a Previously Defined Manufacturing Organization                 │ │
│ │ Select ABC Pencil Co., Shreveport, LA                                     │ │
│ ├───────────────────────────────────────────────────────────────────────── │ │
│ │      Help        Horizontal         Vertical         Select               │ │
│ │      <F1>            ↔                 ↕                ↵                   │ │
│ └───────────────────────────────────────────────────────────────────────────┘ │
└───────────────────────────────────────────────────────────────────────────────┘
```

Figure 7.5:   Main MOSES Menu

```
┌────────────────────────◄MANUFACTURING MODEL MENU►──────────────────────────┐
│ ┌─────────────────────────────────────────────────────────────────────────┐ │
│ │   Global      Background      Input      Go      Output       Quit        │ │
│ └─────────────────────────────────────────────────────────────────────────┘ │
│ ┌─────◄Global►──────┐                                                         │
│ │ Simulation Dates  │                                                         │
│ │ Random Number Seed│                                                         │
│ │ Reporting Interval│                                                         │
│ │                   │                                                         │
│ │ Option 1  of 3    │                                                         │
│ └───────────────────┘                                                         │
│ ┌─────────────────────────◄EXPLANATION►────────────────────────────────────┐ │
│ │ Global Simulation Parameters                                              │ │
│ │ Set today's date and simulation's start and stop dates                    │ │
│ ├────────────────────────────────────────────────────────────────────────── │ │
│ │      Help        Horizontal         Vertical         Select               │ │
│ │      <F1>            ↔                 ↕                ↵                   │ │
│ └───────────────────────────────────────────────────────────────────────────┘ │
└───────────────────────────────────────────────────────────────────────────────┘
```

Figure 7.6:   Manufacturing Model Menu

in conjunction with a number of MOSES default parameters values (e.g., the default simulation period is one day). In most cases, however, the user will not want to begin the simulation process so quickly. Instead, he will select one of the other menu options which allow him to view, change, or print parameter values.

If he selects the Global option, the user can work with such parameters as the random number seed, the simulation start and stop dates, and the simulation results reporting interval. These values may be viewed and changed.

The Background option allows the user to view the parameter values which completely define the manufacturing organization. Recall that no changes can be made to parameters through the Background option; only viewing is permitted.

The Input option is where most of the "action" is located. One of the MOSES premises is that users are only allowed to make changes to the organization's parameters through those functional areas which control the particular parameters. For example, if the user wishes to make changes in a product's ordering pattern, he must first select Marketing under the Input option. MOSES is arranged in this fashion in an attempt to force users to realistically participate in the management of the organization (and, hence, in the simulation process).

For this initial sample run, only two parameter values

are changed. First, the run length is set to two days by selecting Simulation Dates under the Global option on the Manufacturing Model Menu. Second, the reporting interval is also changed to two days. These two changes instruct MOSES to simulate for two working days before stopping and reporting the simulation results only at the termination of the simulation run. The first sample run (i.e., simulation run) is made for the current product ordering parameters. The ordering pattern is shown in Figure 7.4.

The simulation-run process is started by selecting Run under the Go option on the Manufacturing Model Menu. Once the Run option is chosen, MOSES simulates the activities of the ABC Pencil Company by performing a variety of tasks including forecasting, scheduling, order servicing, materials purchasing, materials receiving, production updating, and payment receiving. After simulating two days' activities, MOSES returns control to the Manufacturing Model Menu so that the user can view the results. Figure 7.7 shows the finished product inventory and order servicing situation which resulted from simulating the current ordering pattern for two days. Inspection of the tables leads to the conclusion that inadequate numbers of component parts and raw materials are on hand for this level of demand. Of course, dozens of other conclusions could also be made from other available reports.

For the second sample run, changes are made in the order-

ABC Pencil Co., Shreveport, LA   Date: 05/01/88
Page: 1
                        PRODUCT INVENTORY SUMMARY
                        PERIOD   05/01/88 - 05/02/88

	------------------Orders During Period------------------								Current
Product	Orders		Filled		Backorders		Lost		Number
Number	No.	Amount	No.	Amount	No.	Amount	No.	Amount	in Stock
1	26	741	11	212	15	529	0	0	3
2	27	1814	1	42	26	1772	0	0	0
3	27	2083	4	42	23	2041	0	0	0
4	36	1025	1	23	35	1002	0	0	0
5	17	805	0	0	17	805	0	0	19
6	35	2302	0	0	35	2302	0	0	16
7	27	1090	8	137	19	953	0	0	7

Figure 7.7:   Product Inventory Summary

ing patterns of products 2 and 4. No other parameters are

changed. Figure 7.8 shows the parameters associated with the

new ordering patterns for each one of the ABC Pencil

Company's finished products. Changes are made to the pro-

ducts' ordering patterns by first selecting   Marketing

under the Input option on the Manufacturing Model Menu and

then selecting Product Order Profile, Change under the

Orders option on the Marketing Menu. Figures 7.9 and 7.10

show this sequence. Figure 7.11 shows a change screen where

the actual changes to the product ordering patterns are

made. Figure 7.8 shows that the product ordering pattern

parameters have been changed for products 2 and 4 to reflect

ABC Pencil Co., Shreveport, LA   Date: 05/01/88
Page: 1
                        PRODUCT ORDER PROFILE

Product Number	Product Description	Time Between ---Order Arrivals--- Dist	(Minutes)	----Order Size---- Dist	(Units)
1	Ball Point Pen Type A	UNI	Min = 5.00 Max = 60.00	EXP	Mean = 37
2	Fountain Pen Type A	UNI	Min = 5.00 Max = 90.00	UNI	Min = 25 Max = 100
3	Mechanical Pencil Type	UNI	Min = 5.00 Max = 60.00	EXP	Mean = 67
4	Ball Point Pen Type B	EXP	Mean = 35.00	UNI	Min = 5 Max = 60
5	Fountain Pen Type B	EXP	Mean = 46.00	NOR	Mean = 45 StDv = 5.50
6	Mechanical Pencil Type	UNI	Min = 5.00 Max = 60.00	UNI	Min = 25 Max = 100
7	Ball Point Pen Type C	UNI	Min = 10.00 Max = 70.00	EXP	Mean = 40

Figure 7.8:   Changed Product Order Profile

Figure 7.9:   Selection of Marketing Function

```
┌─────────────────────────◄MARKETING MENU►─────────────────────────┐
│                                                                   │
│     Sales          Orders          Forecast      Modify      Quit │
│                                                                   │
├───────────────────────────────────────────────────────────────────┤
        ┌──────────────◄Orders►──────────────┐
        │ Product Order Profile, Change       │
        │ Product Order Profile, View         │
        │ Product Backorder Policy, Change    │
        │ Product Backorder Policy, View      │
        │                                     │
        │          Option 1  of 4             │
        └─────────────────────────────────────┘

├───────────────────────────◄EXPLANATION►──────────────────────────┤
│ Set Product Orders Parameter Values                               │
│ Set time-between-orders and order size parameter values           │
├───────────────────────────────────────────────────────────────────┤
│      Help          Horizontal         Vertical        Select      │
│      <F1>             ↔                  ↑↓              ↵          │
└───────────────────────────────────────────────────────────────────┘
```

Figure 7.10:   Product Order Profile Change Selection

```
┌══════════════════════════◄MARKETING - ORDERS►══════════════════════┐
│ ABC Pencil Co., Shreveport, LA                       Date: 05/01/88 │
│                                                                     │
│                     PRODUCT ORDER PROFILE                           │
│                                                                     │
│     Product Number: Z                                               │
│     Description: Fountain Pen Type A                                │
│                                                                     │
│                Time Between Order Arrivals (Minutes)                │
│                                                                     │
│     Type of Distribution (UNI/EXP/NOR): UNI                         │
│                                                                     │
│             Minimum:  5   Maximum:  90                              │
│                                                                     │
│                  Product Order Size (Units)                         │
│                                                                     │
│     Type of Distribution (UNI/EXP/NOR): UNI                         │
│                                                                     │
│             Minimum: 25   Maximum: 100                              │
├─────────────────────────────────────────────────────────────────────┤
│ Insert   Delete    Prev Product Next Product Prev Page Next Page  Save  Exit │
│ <F1> <Ctrl><Home> <Ctrl><PgUp> <Ctrl><PgDn> <PgUp>   <PgDn> <Ctrl>W <Esc> │
└─────────────────────────────────────────────────────────────────────┘
```

Figure 7.11:   Change Screen for Product Order Profile

decline in ordering frequency.

The second sample run is initiated by first reseting the Simulation Dates under the Global option and then selecting Reinitialize under the Go option on the Manufacturing Model Menu. After the simulation has run for two working days, the results may be examined. Figure 7.12 shows the finished product inventory and order servicing situation resulting from the new ordering patterns. As is apparent, the ABC Pencil Company is better able to provide products at the reduced ordering levels.

ABC Pencil Co., Shreveport, LA   Date: 05/01/88
Page: 1
                          PRODUCT INVENTORY SUMMARY
                          PERIOD 05/01/88 - 05/02/88

Product Number	Orders		Filled		Backorders		Lost		Current Number in Stock
	No.	Amount	No.	Amount	No.	Amount	No.	Amount	
1	34	1178	8	54	26	1124	0	0	8
2	15	1261	5	405	10	856	0	0	2
3	30	1480	3	41	27	1439	0	0	1
4	25	792	3	213	22	579	0	0	0
5	18	817	0	0	18	817	0	0	19
6	30	1892	0	0	30	1892	0	0	16
7	29	1250	7	64	22	1186	0	0	0

Figure 7.12: Changed Product Inventory Summary

Chapter VIII

CONCLUSIONS AND FURTHER RESEARCH

In their 1975 ACM Turing Award lecture, Newell and Simon had this to say about the concept of research in the context of new evolving disciplines [73]:

> Each new program that is built is an experiment. It poses a question to nature, and its behavior offers clues to an answer. Neither machines nor programs are black boxes; they are artifacts that have been designed, both hardware and software, and we can open them up and look inside. We can relate their structure to their behavior and draw many lessons from a single experiment.
>
> As basic scientists we build machines and programs as a way of discovering new phenomena and analyzing phenomena we already know about.

In short, the objective of this research was to design and develop a computer-based simulation system capable of modeling a computer-integrated manufacturing environment. The model's purpose was to foster understanding of such an environment, to serve as an instructional and research tool for testing and analyzing organizational alternatives, and to provide an interactive, no-programming-necessary system for use by manufacturers. This dissertation discusses the need for such a model and describes the general-purpose, computer-integrated manufacturing simulation model, MOSES, which was developed to fulfill that need. (Note: MOSES is a

122

copyrighted and registered computer program. Its code is not included in the dissertation because of its bulk and because of its potential marketability.)

The MOSES approach to simulation modeling is different from traditional approaches. While this dissertation discusses numerous MOSES innovations and characteristics, the primary contribution of MOSES is probably its conceptual design. In short, MOSES is simple to use and broad in scope, is based on mathematical and logical principles, employs simulation principles and database technology, and includes the user as a integral component of the simulation process. The synthesis of these factors makes MOSES a uniquely useful - and widely applicable - decision-support tool.

MOSES provides a vehicle for examining the manufacturing environment from a "total system" viewpoint. It models the basic functions of the manufacturing environment, simulates their relationships with each other, and shows the immediate effect of a multitude of decisions which are made with respect to those functions. This chapter presents the results of the research effort and describes the unusually large variety of further research possibilities.

8.1   CONCLUSIONS

This research is based on the premise that the key to the successful "factory of the future" lies in the thoughtful integration of management and technology - and that imme-

diate information interchange is a necessary condition for the success of such a system. For such a system to be successful, management needs appropriate tools for considering and checking various strategies and mechanisms and the capability to alter these strategies both while the system is in operation and sometimes before the strategies are implemented.

This research investigated and determined the areas within the manufacturing environment where the need for immediate information is crucial and designed MOSES based on that philosophy. MOSES is not a simulation model of a traditional manufacturing organization. It is a simulation system capable of modeling a manufacturing organization in which the computer is completely integrated throughout. Unlike traditional simulation approaches, MOSES includes mathematical models throughout its structure. But the algorithms are applied from a new perspective. Rather than being depended upon, the mathematical models were included to provide default values which managers are allowed to override. Further, in some cases, multiple algorithms were provided. This arrangement provides the MOSES user with a management laboratory in which to play "spreadsheet-like," "what-if" games - both before and during the simulation process.

Another contribution of MOSES is that it takes a "total system" view of the manufacturing environment. Rather than modeling a specific part of the manufacturing system, MOSES

takes a global view of the manufacturing organization. In particular, MOSES spans the organization from marketing and sales to accounting and shipping. The variety of additional research possibilities which are available as a result of such a model are described later in the chapter.

MOSES uses an innovative integration of database concepts with the more traditional computer-based simulation concepts. In the information-rich environment of the "factory of the future," all the static and dynamic information about the organization and organizational activities will be stored in databases. MOSES takes the view that the future is now and that the information flow between various functions of the manufacturing organization will be performed through databases. This approach of designing a simulation system includes the ability to provide the data in a variety of forms and perspectives which will someday be normally available within the manufacturing organization. Only a DBMS-based simulation system could provide the breadth of views and rapid response contained within MOSES.

Another unique contribution of MOSES, which is only possible because of the DBMS-based structures, is its multi-function arrangement. Users of MOSES provide input to the system through the local, somewhat restricted views of marketing, inventory, production, and accounting. Viewing the manufacturing organization from these varied and limited vantage points is a psychological exercise intended to

broaden the perspectives of MOSES users, to allow them to "walk in the other guy's shoes." While recognizing that cooperation between potentially "contentious" functions within an organization requires more than just understanding the other guy's needs, the developers of MOSES believe that information is a necessary first step.

This research also investigated the appropriateness of using techniques of intelligent simulation in developing a manufacturing organization model. While it is obvious that it is extremely difficult at this point in time to build such a model entirely through the use of the techniques of intelligent simulation, there is a great deal of promise in applying such techniques, especially when intelligent simulation concepts are coupled with traditional computer-based simulation methodology. Limited applications of intelligent simulation were incorporated into the design of MOSES. Investigations performed as a part of the research identified areas where future advancements can be made.

MOSES is a completely menu-driven, interactive simulation modeling tool designed explicitly for the manufacturing environment. It removes the need of the burdensome task of programming in a specialized simulation language from managers and other potential users. Since manufacturing managers are often non-programmers and even more often non-simulation specialists, the structure of MOSES allows them to skip the program development step and to concentrate on

the task of model building from the perspective of develop-
ing accurate manufacturing environment parameter defini-
tions. By using this approach, modelers can concentrate on
the manufacturing organization and the analysis of the
results. It is hoped that MOSES can do for the modeling of
manufacturing systems what the spreadsheet did for financial
planning and projection - provide a powerful and easy-to-use
tool for end-users.

As discussed in Chapter 6, it is difficult - at least in
short term - to validate the simulation results from such a
broad modeling endeavor. The results have been checked
extensively for reasonableness. In addition, the working
model was demonstrated for several different groups of
people - from business, from academics, and from the univer-
sity's Office of Technology Transfer. In each case, the
response was positive. While recognizing that full valida-
tion is not possible, application - and modification - of
MOSES over time will eventually result in implicit model
validation.

8.2 FURTHER RESEARCH

MOSES is a solid beginning. It is a full circle/complete
cycle system simulator capable of accepting orders on one
end and shipping products on the other end. Besides provid-
ing students, researchers, practitioners with a realistic
tool for viewing the manufacturing system environment, it

also serves as a tool for further research in the computer-integrated manufacturing environment.

MOSES' development is based on a new approach to simulation modeling. It combines computer-based intelligent simulation techniques with database concepts, operations research techniques, and heuristic methods. Its interactive design not only allows user interaction, but encourages it. That is, one of the basic premises of the model is that computer technology and mathematical modeling are intended to be servants of man, and not the other way around.

Earlier chapters showed how the current version of the model might be used. The next few sections of this chapter describe some of the potential for further research efforts using MOSES. These MOSES-based research projects may be grouped into at least three distinct, but related, categories.

8.2.1 Relationship Research

The first category may be referred to as "relationship research." A number of possibilities exist for the study and determination of indirect manufacturing environment relationships. For example, the mathematical modeling literature describes numerous inventory models. The models include factors such as demand, carrying cost, holding cost, and shortage cost. Optimum order quantities (sometimes called "economic order quantities" or EOQ's) and optimal reorder

points may be determined based on the modeling results. Such approaches, however, are not concerned with the effect of these inventory policies on other related and important aspects of the organization. For example, while demand is a prominent component in all inventory models, distribution policies which affect the length of time finished products remain in inventory are not. Computer-based, statistical experiments could be designed to determine the affect of various inventory policies on distribution and vice versa. Similar studies might be designed for many other manufacturing environment combinations.

8.2.2   Model Clarity Research

The second category might be called "model clarity" research. The development of MOSES required numerous simplifications to an actual manufacturing system. For example, the current version of MOSES includes production parameters which describe quantitatively the production capabilities of the organization being modeled. Variables such as products per hour and fraction of defective products must be defined. However, an approach such as the current one does not include enough detail to study the minute-to-minute concerns of production scheduling, nor does it include the effects on other related manufacturing system functions. The need to add additional clarity and detail to MOSES is the second important MOSES-based research area.

8.2.3   Computer-Based Enhancement Research

The third MOSES-related research category may be called "computer-based enhancements." While earlier chapters describe the variety of capabilities of the complete, current version of MOSES, the system is by no means finished. For example, future versions of the model will include real-time graphics that show the rise and fall of such key parameters as raw materials and component inventory levels, in-process quantities, "bottlenecks," and the organization's financial situation.

Another computer-based research opportunity is to combine intelligent simulation techniques with the current modeling approaches in at least two ways. One enhancement can be achieved by including the manager's knowledge or perception about effects resulting from various decisions (e.g., the functional relationship between the change in price levels and finished product ordering activities). Ideally, this aspect of the model should be incorporated in a way that makes it possible for the knowledge of the user/ manager to "teach" the model. A second way intelligent simulation can be employed within MOSES is by expanding the model's ability to explain. This will enhance the instructive capabilities of the MOSES program. When the technique is in place, a manager will be able to trace the levels and interactions between various factors which led to a particular outcome and may then better understand the significance of the

parameter and its relationships with other input values.

8.3   PROJECTS

This section describes a number of research projects which are directly related to MOSES. Fortunately, there is no way to make the list complete. As MOSES users become more familiar with its capabilities and as more detail is added to the MOSES modeling environment, questions and research opportunities will continue to surface. Still, this list is intended to serve as a starting point for MOSES-based, manufacturing systems research.

8.3.1   Manufacturing Environment Relationship Research

1. The Effect of Inventory Policies on the Distribution System (described earlier in this section).

2. The Effect of High Volume, Erratic Sales Orders on the Manufacturing Environment.

3. The Effect of Forecasting Accuracy (and Inaccuracy) on the Manufacturing Environment.

4. The Effect of Real-Time Management Overrides in a Computer-Controlled Manufacturing Environment.

8.3.2   Model Clarity Research

1. The Development of a MOSES-Based Generalized Production System (described earlier in this section).

2.   Enhancing MOSES by Applying It.

The accuracy and usefulness of detail included in any computer-based, manufacturing model is dependent on the understanding and experience of the modelers. While no one can claim complete knowledge with regard to a system such as the one modeled by MOSES, there is no doubt, however, that the experience and understanding of various users - if taken seriously - can further enhance the model. The MOSES model is founded on manufacturing system experience and research, but its application to real manufacturing situations not only has the potential to benefit the manufacturers but will also help to uncover possible inconsistencies within MOSES, as well as to point out appropriate additions.

8.3.3   Computer-Based Enhancement Research

1.   Graphics Enhancements to the MOSES-Based Manufacturing Simulation (described earlier in this chapter). Graphical displays in the form of graphs, charts, and plots are a much needed enhancement to the usefulness of MOSES as an analytical tool.

2.   MOSES-TEACH, the Manufacturing Organization Instructor. The purpose of this research effort is

to enhance the MOSES system in terms of instructional usefulness. Because of its style, structure, and content, MOSES could become a kind of "living book" on the manufacturing environment. Currently existing HELPs describe the various pieces of MOSES (e.g., "The Product Bill of Materials is..."), but "teach" keys could be added throughout the system to describe possibilities for managers, point out key parameters to watch, and provide rules-of-thumb.

3. MOSES-EXPERT, Expert System Enhancements to the Manufacturing Environment Simulator. The purpose of this type of research is to enhance the capabilities of MOSES by providing expert systems throughout. The inclusion of appropriate expert systems could enhance MOSES' "what if" capabilities and aid the heuristic decision-making capabilities of users.

8.4 IMMEDIATE IMPROVEMENTS

Viewed from still another perspective, the immediate improvements that can be made to MOSES can be grouped into two, easy-to-understand categories: hardware improvements and software improvements.

8.4.1   Hardware Improvements

With respect to hardware, MOSES should be ported to a computer system with a higher processor speed. This could dramatically increase the speed of individual simulation runs and could improve the user's analysis abilities. Few things annoy and disrupt users trying to analyze a situation like being forced to wait on a computer to respond. The typical result is that the user's train of thought is broken. This means that the net negative impact on work is much more than the loss of a few seconds spent "waiting for the screen." A thorough, well-planned study should be conducted on the model using a range of inputs and scenarios to assess the responsiveness and capabilities of MOSES.

Hardware improvements are primarily the result of the availability of money. New microcomputer systems based on the Intel 80386 microprocessor are already in the market, some possessing clock speeds of 20 Megahertz. Simply running MOSES on such a machine should provide at least a three fold improvement in its processing speed when compared to present implementations. Of course, another logical alternative is to rewrite the software for implementation on a distinctly different level of machine, such as the DEC VAX 8800 or a DEC MicroVAX.

8.4.2   Software Improvements

On the software side, an investigation should be conducted

into the feasibility of implementing the simulation portion of MOSES in a compiler-based high-level language. One of the features of dBASE III PLUS which makes it easy to debug is the fact that the language is interpretive. Unfortunately, the same feature is a disadvantage in terms of processing speed once the code is correctly in place. This potentially rather simple change has the possibility of a dramatic impact on the model's response time - without sacrificing the usefulness of the current implementation. In fact, a new version in the dBASE series called dBASE IV is already on the market. According to the literature, dBASE IV code can be compiled and will speed up program execution. Another slightly less direct strategy might be to write the simulation portion of the program in a completely different language (such as Turbo Pascal) and interface that language with the database definition manipulation commands of dBASE III PLUS.

In summary, MOSES is a potentially valuable tool for instruction, research, and industrial applications. In addition, its potential for future growth is significant.

REFERENCES

1.   Tompkins,   J.A.,   "Computer-Integrated Manufacturing
      Update," Proc. of Fall 1986 Industrial Engineering
      Conference, pp 125-126.

2.   Rosenthal,   S.R.,   "Progress   Toward the   'Factory   of
      Future'," Journal of Operations Management, Vol. 4,
      No. 3, May 1984, pp 203-229.

3.   "Management Guide for CIM," The Computer and Automated
      Systems Association of SME, 1986, pp 5.

4.   Casti, J.L., "Metaphors for Manufacturing: What Could
      It Be Like to Be a Manufacturing System?" Technologi-
      cal Forecasting and Social Change, Vol. 29, No. 3,
      1986, pp 241-270.

5.   Tompkins, J.A. and J. A. White, "Facilities Planning,"
      Wiley, 1984, pp 394.

6.   Turner Wayne C., et al., "Introduction to Industrial
      and Systems Engineering," Second Edition, Prentice-
      Hall, NJ, 1987, pp 26.

7.   Merchant, M.E., "The Factory of the Future – Technolo-
      gical Aspects," The Bridge, National Academy of Engi-
      neers, Vol. 11, No. 1, Spring 1981, pp 25-31.

8.   Hymowitz, C., "Manufacturing Change: A Special Report
      on Technology in the Workplace," Wall Street Journal,
      September 16, 1985, pp 10c-12c.

9.   "The National Role and Importance of Manufacturing
      Engineering and Advanced Manufacturing Technology,"
      Position Paper by The Society of Manufacturing Engi-
      neers, Dearborn, MI, May 1978.

10.   "Toward a New Era in U.S. Manufacturing," Manufactur-
      ing Studies Board, National Research Council, National
      Academy Press, Washington, D.C., 1986.

11.   Ashburn, A., et al., "Machine Tool Technology," Spe-
      cial Report No. 726, American Machinist, October 1980,
      pp 105-128.

12. Weisel, W.K., "The Robot's Role in Productivity," Production Engineering, Vol. 28, No. 12, December 1981, pp 18-19.

13. Merchant, M.E., "Production: A Dynamic Challenge," IEEE Spectrum, May 1983, pp 36-39.

14. Kutcher, M., "Automating it all," IEEE Spectrum, May 1983, pp 40-43.

15. Ingersoll Engineers, "Integrated Manufacture," IFS Publications, Bedford, MA, 1985.

16. Mize, Joe H. and D.J. Seifert, "CIM - A Global View of the Factory," Proc. of 1985 Annual Industrial Engineering Conference, pp 173-177.

17. Harrington, Joseph, "Computer-Integrated Manufacturing," Industrial Press, New York, 1973.

18. "Computer-Integrated Manufacturing Glossary," The Society of Manufacturing Engineers, Dearborn, MI, 1984.

19. Boaden, R.J., et al., "What is Computer-Integrated Manufacturing?" International Journal of Operations and Production Management, Vol. 6, No. 3, 1986, pp 30-37.

20. Groover, M.P. and E.W. Zimmers, "CAD/CAM," Prentice-Hall, NJ, 1983.

21. Sadowski, R.P., "Computer-Integrated Manufacturing Systems will Apply Systems Approach to the Factory of the Future," Industrial Engineering, Vol. 16, No. 1, 1984, pp 35-40.

22. Willis, R.G. and K.H. Sullivan, "CIM in Perspective: Costs, Benefits, Timing, Payback Periods are Outlined," Industrial Engineering, Vol. 16, No. 2, 1984, pp 28-36.

23. Vernadat, F., "Communications: A Key Requirement in Computer-Integrated Manufacturing," Second Annual Phoenix Conference on Computers and Communications, Phoenix, AZ, March 1984, pp 193-198.

24. Otten, K.W., "Information Systems for Engineering and Manufacturing: CAE, CAD, CAM, CIM," Journal of Information and Image Management, Vol. 17, No. 5, 1984, pp 25-30.

25. Harrington, Joseph, "Understanding the Manufacturing Process: Key to Successfull CAD/CAM Implementation," Marcel Dekker, NY, 1984.

26. Lardner, J.F., "Unpublished ICAM Industry Days Address," New Orleans, LA, May 1982.

27. Waterlow, J.G., "Manufacturing Systems Research: Where are the Boundaries?" International Journal of Operations and Production Management, Vol. 3, No. 3, 1983, pp 49-59.

28. Francis, N.D., "Simulation of Manufacturing System," Proc. of 1981 UKSC Conference on Computer Simulation, pp 90-96.

29. Dunham, N.R. and A.K. Kochhar, "Interactive Computer Simulation for the Evaluation of Manufacturing Planning and Control Strategies," Proc. of 1981 UKSC Conference on Computer Simulation, pp 82-89.

30. Buzacott, J.A., "Modeling Automated Manufacturing Systems," Proc. of Fall 1983 Industrial Engineering Conference, pp 341-348.

31. Cohen, P.H. and R.A. Wysk, "Digital and Physical Simulation of Manufacturing Systems," Proc. of 1984 Winter Simulation Conference, pp 381-383.

32. O'Reilly, J., et al., "The Use of Continuous/Discrete Event Models in Manufacturing," Proc. of 1985 Winter Simulation Conference, pp 308-314.

33. Krajewski, Lee, et al., "The Simulation of Real Manufacturing Systems for the Improvement of Inventory, Productivity, and Service," Proc. of Fall 1982 Industrial Engineering Conference, pp 241-249.

34. Engelke, H., et al., "Integrated Manufacturing Modeling System," IBM Journal of Research and Development, Vol. 29, No. 4, July 1985, pp 343-355.

35. Lee, Hau and Edison Tse, "An Integrated Approach to Manufacturing Enterprise," an IBM supported Project through the Center for Teaching and Research in Integrated Manufacturing Systems, Stanford University, SIMA Status Report, 1986.

36. "General-Purpose Manufacturing Simulation," IBM Technical Disclosure Bulletin, Vol. 29, No. 5, October 1986, pp 2063.

37. Crookall, J.R., "Computer Integration of Advanced Manufacture," Proc. of Institution. of Mechanical Engineers, Vol. 200, No. B4, 1986, pp 257-264.

38. Pruett, James M., "Computer-Integrated Manufacturing Instructional and Research Model," a proposal funded by The Society of Manufacturing Engineers' Manufacturing Engineering Education Foundation, 1983.

39. Lindeque, P. and P.S. Kruger, "The Design of a Micro-computer Based Simulator for Production Management Training," Computers and Industrial Engineering, Vol. 14, No. 1, 1988, pp 53-62.

40. Nof, Shimon, "An Expert System for Planning/Replanning Programmable Facilities," International Journal of Production Research, Vol. 22, No. 5, 1984, pp 895-903.

41. Fox, M.S., et al., " Job-Shop Scheduling: An Investigation in constraint-Directed Reasoning," Proc. of the 2nd National Conference on Artificial Intelligence, August 1982, pp 155-158.

42. Ben-Arieh, D., "Manufacturing Systems Application of a Knowledge Based Simulation," Proc. of the 8th Annual Conference on Computers and Industrial Engineering, 1986, pp 459-463.

43. Kumara, S.R.T., et al., "Expert System for Industrial Facilities Layout Planning and Analysis," Computers and Industrial Engineering, Vol. 12, No. 2, 1987, pp 143-152.

44. Conway, R., et al., "User's Guide to XCELL+ Factory Modeling System," The Scientific Press, Redwood City, CA, 1987.

45. Miner, R.J. and L.J. Rolston, "MAP/1 User's Manual," Pritsker and Associates, Inc., West Lafayette, IN, 1987.

46. "SIMFACTORY," CACI Inc., Campbell, CA, 1986.

47. Shannon, R.E., "Systems Simulation - The Art and Science," Prentice-Hall, NJ, 1975.

48. Crookall, J.R. and J. Bollinger, "The Role of Simulation in Design/Teaching of Manufacturing Systems," Annals of CIRP, Vol. 30, No. 2, 1981, pp 525-532.

49. White, C.H., "The Factory of the Future and Simula-

tion: An Overview," Proc. of 1983 Winter Simulation Conference, pp 119-123.

50. Pegden, C.D., "Introduction to SIMAN," Systems Modeling Corporation, State College, PA, 1983.

51. Beaumariage, T.G. and J.H. Mize, "Simulation Model Developer," Proc. of May 1987 Industrial Engineering Conference, pp 147-153.

52. Britton, H.O. and W.E. Hammer, Jr., "Designers, Users, and Managers Share Responsibility for Ensuring CIM Systems Integrity," Indutrial Engineering, May 1984, pp 36-48.

53. Yancey, D.P., "Database Management Systems can Provide Way to Manage Information Created in a Computer Simulation Program," Industrial Engineering, May 1987, pp 50-53.

54. Standridge, C.R. and A.A.B. Pritsker, "Using Database Capabilities in Simulation," Proc. of 1980 Simulation Conference, Interlaken, Switzerland.

55. Trigeiro, W.W., "A Dual-Cost Heuristic for the Capacitated Lot Sizing Problem," IIE Transactions, Vol. 19, No. 1, March 1987, pp 67-72.

56. Benli, O.S., et al., "A Heuristic Procedure for Single-Item Dynamic Lot Sizing Problem," Computers and Industrial Engineering, Vol. 14, No. 2, 1988, pp 181-192.

57. Afentakis, P., "A Parallel Heuristic Algorithm for Lot Sizing in Multistage Production Systems," IIE Transactions, Vol. 19, No. 1, March 1987, pp 34-42.

58. Glover, F., et al., "A Heuristic Programming Approach to the Employee Scheduling Problem and Some Thoughts on 'Managerial Robots'," Journal of Operations Management, Vol. 4, No. 2, February 1984, pp 113-128.

59. Klahr, P. and W.S. Faught, "Knowledge Based Simulation," Proc. of the First National Conference of the American Association for Artificial Intelligence, 1980, pp 181-183.

60. Shannon, R.E., et al., "Expert Systems and Simulation," Journal of Society for Computer Simulation, Vol. 44, No. 6, June 1985, pp 275-284.

61. Reddy, R., "Epistemology of Knowledge Based Simulation," Journal of the Society for Computer Simulation, Vol. 48, No. 4, April 1987, pp 162-166.

62. Ford, D.R., et al., "An Expert Manufacturing Simulation System," Journal of the Society for Computer Simulation, Vol. 48, No. 5, 1987, pp 193-200.

63. Hill, T.R., et al., "A Prototype Knowledge-Based Simulation Support System," Journal of the Society for Computer Simulation, Vol. 48, No. 4, April 1987, pp 152-161.

64. Moser, J., "Integration of Artificial Intelligence and Simulation in a Comprehensive Decision-Support System," Journal of the Society for Computer Simulation, Vol. 47, No. 6, Dec. 1986, pp 223-229.

65. Michie, D., "Expert Systems: Past Problems and New Opportunities," Proc. of IBM Engineering Scientific Study Conference, Nov. 1982, New York, pp 19-45.

66. Dijkstra, E.W., "A Discipline of Programming," Prentice-Hall, New York, 1976.

67. Hill, I.D., "Structured Programming," in Guide to Good Programming Practice, Edited by B.L. Meek and P.M. Heath, Ellis Harwood Ltd., Chichester, U.K., 1980.

68. "Learning and Using dBASE III PLUS," Ashton-Tate, Torrance, CA, 1986.

69. "Programming with dBASE III PLUS," Ashton-Tate, Torrance, CA, 1986.

70. "Turbo Pascal 3.0 User's Manual," Borland International Inc., Scotts Valley, CA, 1985.

71. Payne, J.A., "Introduction to Simulation: Programming Techniques and Methods of Analysis," McGraw-Hill, New York, 1982.

72. Biles, W.E. and J.J Swain, "Optimization and Industrial Experimentation," Wiley, New York, 1980.

73. Newell, A. and H.A. Simon, "Computer Science as Empirical Inquiry: Symbols and Search," Communications of the ACM, Vol. 19, No. 3, March 1976, pp 113-126.

APPENDIX A

GENERAL ASSUMPTIONS

1. The model should work with any number of independent products within a manufacturing environment having limited production capacity and limited levels of raw materials. (Note: The number of products which MOSES can handle is limited only by the disk storage space available.)

2. Each product should have its own bill of materials. Each bill of materials may be composed of purchased parts, fabricated parts, or subassemblies. The fabricated parts (which may be included within one or more subassemblies) are manufactured within the organization's production facility from raw materials purchased, from external vendors. Therefore, fabricated parts have, in effect, their own bills of material. Subassemblies may be purchased in an already-assembled form (e.g., the ballpoint/tube/ink assembly in a ballpoint pen) or may be made up of a combination of purchased and fabricated parts. Purchased parts are obtained from external vendors.

3. Production processes consist of parallel or grouped manufacturing facilities and assembly lines. These

142

groups manufacture and assemble both finished products
and fabricated component parts. This means that MOSES
is not concerned with the problems associated with
product mix.

APPENDIX B

MARKETING FUNCTION ASSUMPTIONS

1. The default method of demand forecasting is a one-period moving average.

2. Orders may arrive at any time during the daily working hours. The time between orders for the individual products and the quantity of product ordered are each distributed according to some standard distribution.

3. Orders are filled as soon as they are received if the entire order quantity is available. Once filled, the order is sent to shipping for distribution to the customer.

4. If the order cannot be filled completely from the stock on hand when the order arrives, it is back-ordered.

APPENDIX C

INVENTORY FUNCTION ASSUMPTIONS

1. Purchased materials are ordered based on the purchase review which is done following the preparation of the current production schedule.

2. Purchased materials are received every day at the end of the day.

3. Payments for the purchased materials are made by the accounts payable function according to the accounts payable policy set in the accounting function.

4. Amount receivable for the orders filled becomes due according to the policy set by accounts receivable subfunction in the accounting function.

5. Order quantity for any purchased material is computed based on economic order quantity. The user can override this function any time.

APPENDIX D

PRODUCTION FUNCTION ASSUMPTIONS

1. The periodic production planning is done based on the sales forecast, backorders, and desired quantity of stock-on-hand at the end of the period for production planning.

2. Provision is made in production planning for scrap during the production process.

3. Planning period can be set to any length in number of days and it can be different from the forecasting period.

4. Daily working hours are based on one shift of 8 hours (480 minutes). Work is planned for every day of the week without any holidays.

5. Weekly and daily capacity is fixed and consequently the hourly production rate determines the limit on the amount which can be produced every hour based on the production capacity. For now this cannot be changed.

6. Whenever there is a production update, first backorders are filled before updating stock available.

APPENDIX E

ACCOUNTING FUNCTION ASSUMPTIONS

1. Accounts Payable policy sets the number of days after which payment is made for a particular account. This time is deterministic in nature.

2. Number of days after which payment is received is a random variable with a normal distribution.

VITA

Vinay Kumar Vasudev was born in Ferozepur City, India on November 25, 1952. He earned a B.S. with Honors in Mechanical Engineering in November, 1974 from Ranchi University in Ranchi, India. Mr. Vasudev then worked as a Mechanical Engineer for more than five years at Indian Petrochemicals Corporation Ltd., Baroda, India before beginning graduate studies at Louisiana State University in August, 1981.

At L.S.U., Mr. Vasudev obtained an M.S. in Industrial Engineering in August, 1983. He worked as a graduate research/teaching assistant from 1981 to 1983. In 1983, he joined the faculty of the Industrial Engineering Department at L.S.U. as an instructor and enrolled simultaneously in the Ph.D. program in Engineering Science. For three and one-half years, Mr. Vasudev pursued his graduate studies on a part-time basis. He left the position of instructor in December, 1987 to pursue the Ph.D. on a full-time basis.

Mr. Vasudev is married to Rama Vasudev. They have one son, Kapil Dharm Vasudev, born in October, 1986.

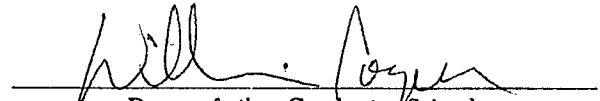# DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Vinay K. Vasudev

Major Field: Engineering Science

Title of Dissertation: Development of a Computer-Integrated Manufacturing Simulation
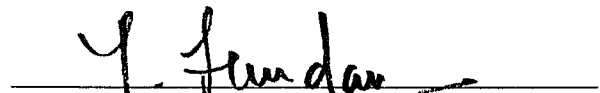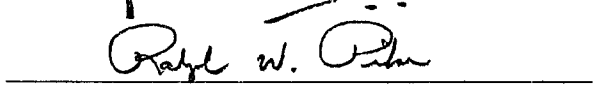Model: A Hybrid Systems Approach

Approved:

_____
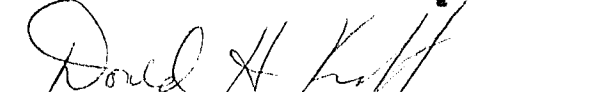Major Professor and Chairman

_____
Dean of the Graduate School

EXAMINING COMMITTEE:

_____

_____

_____

_____

_____

_____

Date of Examination:

April 27, 1988