AN INVESTIGATION OF ALTERNATIVE DAMPENING PROCEDURES TO COPE WITH MRP SYSTEM NERVOUSNESS

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ABSTRACT

AN INVESTIGATION OF ALTERNATIVE
DAMPENING PROCEDURES TO COPE WITH
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Over the last decade, MRP systems have become a dominant technique in production and inventory management. They help manufacturing firms reduce inventory, increase operating efficiency, and improve custormer service. However, few MRP users enjoy enjoy great success with MRP systems. System nervousness, one of the operational problems of MRP systems, has been a concern of both practitioners and academicians. MRP system nervousness refers to frequent changes in due dates and/or quantities of open orders for either purchased or manufactured items.

Dampening procedures are one means to reduce MRP system nervousness in order to minimize the negative effects of system nervousness. The objectives of this research are to analyze and measure MRP system nervousness conceptually and operationally; to evaluate selected dampening procedures; and, to develop and evaluate the cost-based dampening procedure and compare it with other dampening procedures.

A simulation experiment using a multi-product and multi-stage simulated factory was conducted to achieve the research objectives. A

four-factor factorial design (dampening procedure, lot-sizing rule, uncertainty level and capacity utilization level) was used to evaluate the effectiveness of the dampening procedures tested. The primary performance measure was the total related cost and some secondary performance measures, such as shortage cost, were also collected to examine the performance of dampening procedures in further detail.

An analysis of the experimental results first indicated interaction effects existing among the four experimental factors. This implies that operating conditions must be examined together rather than independently to compare the performance of dampening procedures tested. The results indicate that the performance of a dampening procedure is not significantly different from any other dampening procedure in most of the operating conditions examined. Other decision criteria may be used to select an appropriate dampening procedure depending upon the emphasis of an individual firm. Nevertheless, the cost-based dampening procedure generally performed better than the automatic rescheduling procedure in terms of the finished goods tardiness.

The findings reported in this study have important implications for both practitioners and academicians. Some guidelines are proposed to help material planners select an appropriate dampening procedure to cope with MRP system nervousness. To academicians, some misunderstandings regarding MRP system nervousness are discussed and several suggestions for future reseach are provided.

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DEDICATION

To Ting-ing and Eric.

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CHAPTER ONE

INTRODUCTION

Over the last decade, material requirements planning (MRP) systems have become a dominant technique in production and inventory management. An MRP system that is well designed and successfully implemented helps manufacturing firms reduce inventory, increase operating efficiency, and improve customer service (Anderson and Schroeder, 1979). Very few MRP users, however, enjoy great success with MRP systems. An MRP system is a very complicated production scheduling and inventory control technique, which needs to be updated frequently in order to reflect unplanned events, like machine breakdowns, that exist within (e.g. machine breakdown) or outside (e.g. vendor/fall-down) of the production system. This so-called rescheduling capability of MRP systems, by realigning the due dates with the need dates, maintains the integrity of priority. However, the price paid for the frequent disruption of open orders is a major operational problem of MRP systems, which is generally referred to as "system nervousness". The problem facing the MRP user is that of trying to maintan a proper level of priortiy integrity without exposing the system to excessive "shocks" due to a high level of rescheduling. This is the problem examined by this research.

The objective of this research is to investigate MRP system nervousness which results from the MRP system's capability to realign the actual need dates with due dates. A brief review of MRP system is undertaken in this chapter, and various definitions of MRP system nervousness are provided, along with the conceptual framework used to analyze this problem. Dampening procedures are then introduced as one way to cope with MRP system nervousness. The significance of the study is presented to support the need for the research. This discussion is followed by an overview of research methodology. Finally, the order for presenting this thesis is described.

MRP - An Overview

According to Orlicky, over 1000 major manufacturing firms had installed MRP systems by 1975 (Whybark & Williams, 1976, p. 595). The extensive use of MRP systems in production and inventory control was confirmed by Anderson and Schroeder (1979). Actually, the logic behind MRP systems has existed for many years, under different names, such as "quarterly planning system" (Melnyk, 1980). The delay in MRP system implementation was a function of the huge requirements for data handling capacity and the need for relatively cheap computing power (Orlicky, 1975). The enormous computing capacities of computer systems that have become available in the last decade have made MRP systems implementable.

Wight (1981) indicated that there have been four stages in the evolution of MRP system: a better ordering method, priority planning, closed loop MRP, and finally MRP II (otherwise referred to as Manufacturing Resource Planning). Initially, MRP was viewed as an inventory control system which replaced classical inventory control techniques. MRP then evolved into a production scheduling technique which could determine priorities for shop and purchase orders. One of the most important functions of an MRP system, the rescheduling capability, emerged at this stage of development. In the third stage, closed loop MRP system incorporated capacity planning, shop scheduling, and vendor scheduling in the planning system. Finally, MRP II added other features, such as financial planning and simulation capability, to serve as an overall planning system for an entire organization.

The logic of MRP is straightforward. It starts with a Master Production Schedule (MPS) which is the statement of whole prodution requirement broken down by time period and major product line of a manufacturing firm. The MPS specifies quantities and timing needed for each end product. An MRP system then explodes the MPS, using a bill of materials, into the lower level requirements needed to support the MPS. Net requirements are then obtained by netting out on-hand inventory and scheduled receipts. A lot-sizing rule is then applied to these time-phased net requirements. Finally, the order release dates are determined by "offsetting" lead time. It is noteworthy that this lead time offsetting feature is similar to PERT's backward scheduling, making it possible to determine the latest start date for a manufacturing activity.

This simple logic can be better explained by an MRP schedule, as shown in Figure 1.1. Gross requirements represent how many of this inventory item are needed and when, such as 20 in period 1, 50 in period 3, and so on. Scheduled receipts show the quantity of released orders expected to be completed at one period. On-hand inventory is the expected ending inventory for each period. Negative on-hand inventory indicates the need for new orders. In some MRP schedules, net requirements are put in a separate row to represent negative on-hand

Lead time: 2 weeks

Lot-sizing: Lot-for-lot

		Week							
		1	2	3	4	5	6	7	8
Gross Requirements		20		50			90		90
Scheduled Receipts		70							
On Hand	10	60	60	10	10	10	-80	-80	-170
Planned Order Releases					80		90		

Figure 1.1 An Example of MRP Schedule

inventory for each period (Orlicky, 1975). Finally, if the lot-for-lot lot-sizing rule is used for this item, a planned order release is scheduled at a period by lead time offsetting. For instance, the first necessity to replenish this item is in period 6. Because the lead time required to produce this item is 2 weeks, the production of this item should be scheduled to start at period 4.

An MRP system exploits the dependent relationships among product levels in projecting future requirements. MRP depends upon accurate, up-to-date information provided by the MPS, bill of materials, on-hand inventory record, and appropriate estimate of lead times. Furthermore, success in implementing an MRP system relies on discipline in transaction reporting, and physical control over inventories (IBM, 1972, Chapter 5, p. 41).

MRP systems have achieved acceptance in manufacturing firms since 1970 (Anderson and Schroeder, 1979, p. 13). Benefits frequently mentioned are lower inventory cost, higher operating efficiency, and better customer service. However, MRP systems are not without fault. When the changes in open orders disrupt the priority planning frequently, the negative effects of MRP system nervousness arise. This research investigates this operational problem of MRP systems.

MRP System Nervousness

In the literature, MRP system nervousness is described in various ways. Carlson, Jucker and Kropp (1979) defined system nervousness as the shifting of scheduled setups. Mather (1977, p. 69) provided a more detailed definition of MRP system nervousness: "changing the required due date on a related replenishment order for either purchased or manufactured material." Recently, Penlesky (1982, p. 6) defined system nervousness as "the adverse effect that can arise in scheduling systems that use a dynamic due date maintenance procedure."

From these various definitions, it is apparent that MRP system nervousness is only a symptom which simply reflects uncertain events occurred, such as in machine breakdowns or emergency orders. The actual problem is caused by frequent changes that makes the material planners unable to react promptly. Thus, Steele (1975) defined a nervous MRP system as one that generates an excessive number of rescheduling messages. Peterson (1975) gave an example of scheduling instability: an open order may be increased in week 1, decreased in week 2, increased again in week 3, and cancelled in week 4. Such a nervous production schedule makes production planners unable to react adequately on a timely basis. Orlicky (1975a, p. 169) indicated that "probably the most serious problems that an inventory planner must cope with are discrepancies or misalignments between net requirements and coverage, resulting from unplanned events or increases in gross requirements" (p. 169).

Basically, an MRP system is a highly coordinated manufacturing information system which has considerable interactions with other production subsystems, as shown in Figure 1.2. If any unexpected disruption occurs in a subsystem, such as an equipment malfunction on the shop floor, the due date replanned by the MRP system must be adjusted in order to reflect this change. For instance, a machine breakdown on the shop floor may lead to the delay of some shop orders that may, in turn, require expediting to meet the scheduled due date.

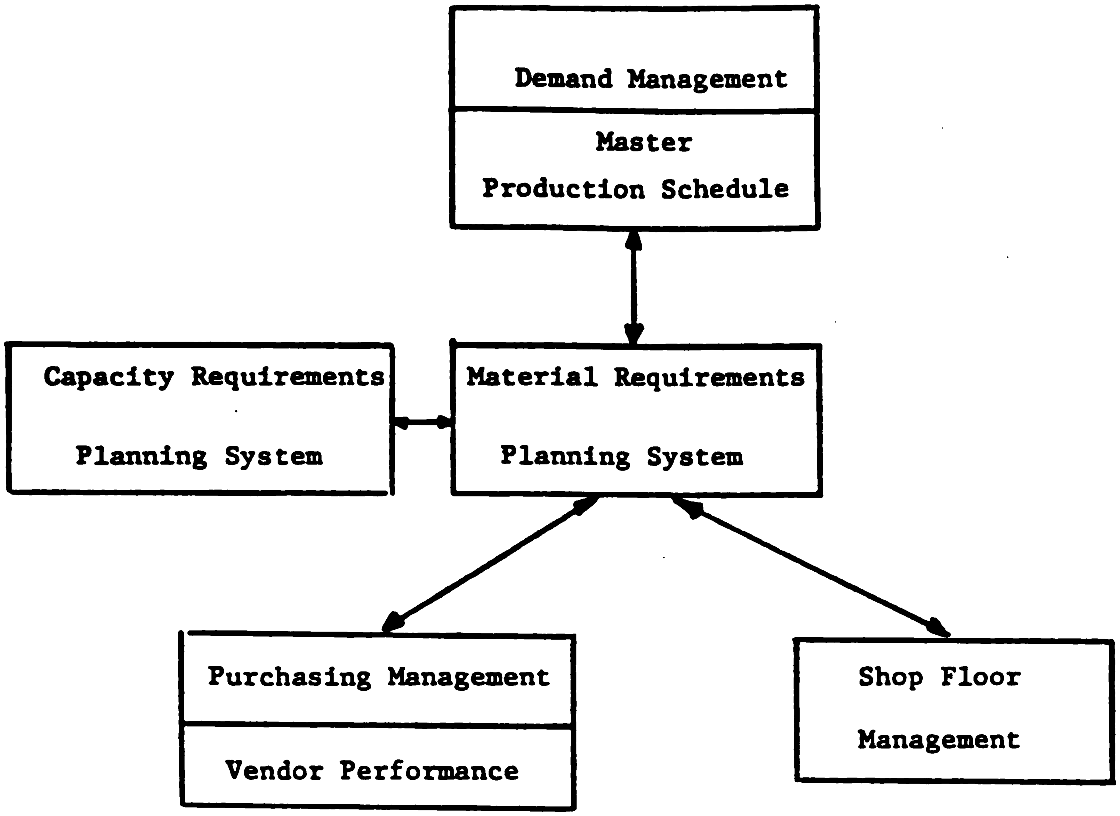


Figure 1.2 Interaction Between MRP System and Other Production Subsystems

If these orders cannot be expedited to meet the original due date, other options should be taken. The due date can be rescheduled to a later date, or the production scheduler can just hope that the delay can be made up during the production of the higher level item (Buffa & Miller, 1979, pp. 353-354).

The conceptual framework of this study is described in Figure 1.3. Any kind of uncertainty problem, that exists within or outside the production system, may create the need for rescheduling. There are two types of external factors that are considered in the production environment. The capacity utilization level, treated as an experimental factor, is determined by the demand loading externally. The other factor is the MPS change which represents environmental uncertainty resulting from the changes of customer orders. Scrap problems represent system uncertainty that occurs within the production system. The selection of a lot-sizing rule is viewed as an internal decision, which is also treated as an experimental factor.

The need to realign the due date and the need date is indicated by rescheduling message generated by the MRP system. The recommended action can expedite, delay, increase, decrease, or cancel the order. The rescheduling messages are then passed through a dampening procedure which screens out "insignificant" rescheduling messages, depending on the decision criterion used in that dampening procedure. Those rescheduling messages which need to be implemented become "rescheduling notices". Thus, in this study rescheduling notices are defined as the "significant" rescheduling messages to be implemented by revising the due dates of open orders. Then, the simulation of the hypothetical factory continues for another week of operation until a specified length

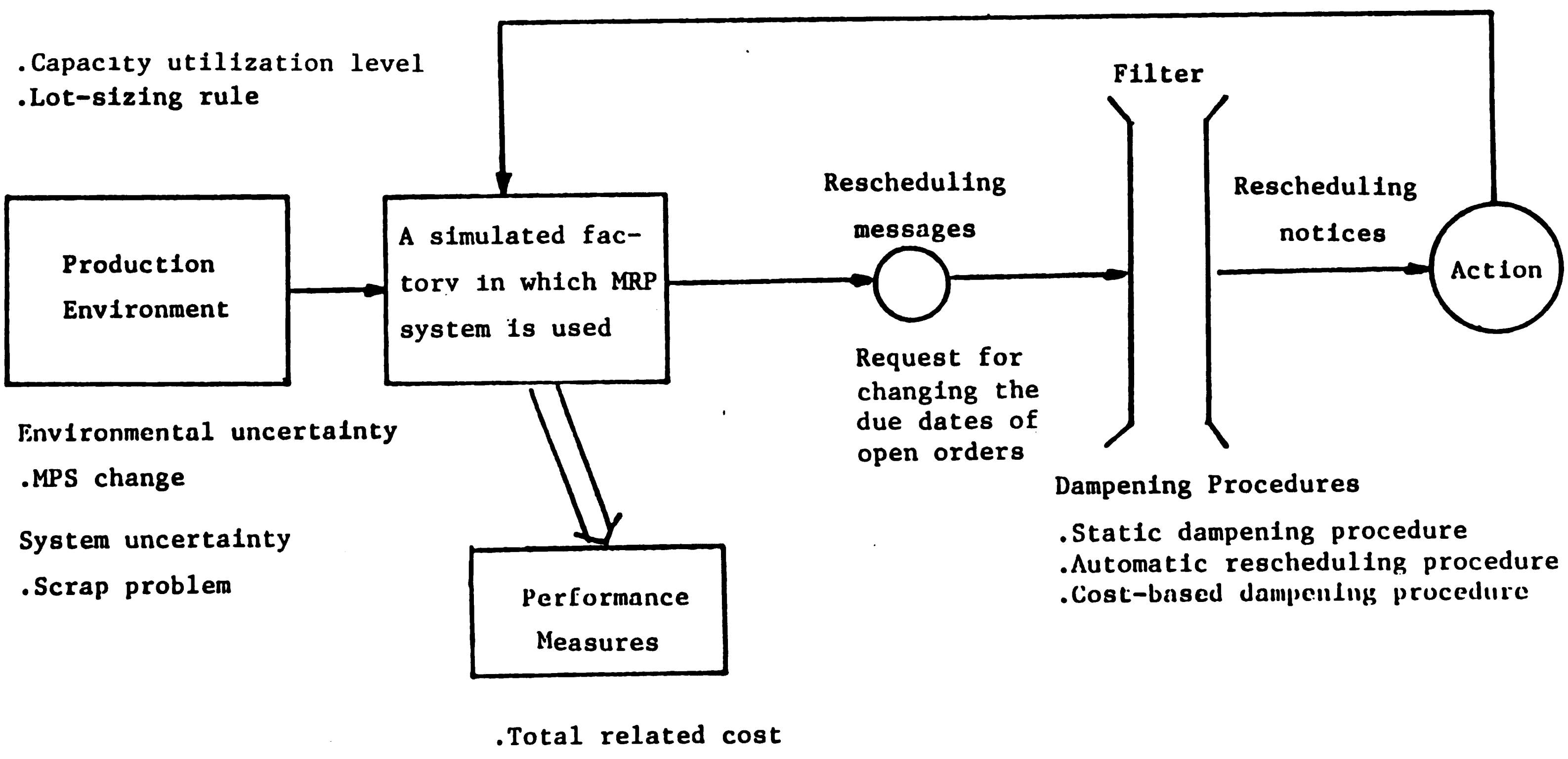


Figure 1.3 Conceptual Framework

of simulation time is reached. Several important performance measures are collected to evaluate the effectiveness of dampening procedures tested.

When a production system is disrupted frequently, the problem of system nervousness arises. Consequently, not only may the total cost increase, but the service level may deteriorate. Credibility of the formal priority planning system may also be jeopardized. This is a major concern since MRP attempts to become a formal credible priority planning system. The question is how best to apply dampening procedures in order to cope with MRP system nervousness.

It should be noted that rescheduling capability is an important function of an MRP system (Orlicky, 1976, p. 38). It is important for an MRP system to keep the due dates current, and, in turn, to maintain the priority integrity. It is the implementation of excessively large number of rescheduling messages that causes the scheduling instability problem. Unnecessary rescheduling messages should be screened out to allow planners sufficient time to analyze significant rescheduling messages. More importantly, capacity utilization will not fluctuate seriously, and excessive rescheduling cost can be avoided.

Dampening Procedures Defined

The American Production and Inventory Control Society (APICS) defined dampeners as "user input parameters to suppress the reporting of insignificant or unimportant action messages created during the computer processing of MRP" (APICS Dictionary, 1980, p. 7). Carlson (1980, p. 19) simply defined "dampening" as "broadening out-of-bound criteria."

In this study, "dampeners" and "dampening procedures" are used interchangably.

From the conceptual framework (Figure 1.3), a dampening procedure can be viewed as a filter which screens out insignificant rescheduling messages. The insignificant rescheduling messages are those which are expected to have little negative impact on the ability of production scheduling system to meet the desired due date. In contrast, the messages not eliminated by dampening filter are considered significant and should be implemented.

Dampening procedures can be divided into "local" or "global" categories. The difference between these two categories is the scope of uncertainty problems that they resolve. "Local" dampening procedures, such as pegged-requirements and lead time compression, deal with a specific type of uncertainty problem. For example, a quantity increase type of uncertainty problem may be resolved by pegged-requirements. The pegged-requirements technique is used to retrieve the gross requirements of the component item to its source (Orlicky, 1977, p. 162). "Global" dampening procedures, in contrast, are designed to handle any type of production uncertainty. These rescheduling messages are classified into significant or insignificant, according to various criteria. Actions are then taken to react to these significant rescheduling messages.

The degree of complexity of a global dampening procedure depends upon the criterion used to classify rescheduling messages. The global dampening procedure suggesed by Mather (1977) and Peterson (1975) is static. That is, once the parameters used in this global dampening procedure is determined, it will not be changed. The static dampening procedure uses the magnitude of timing change of open orders as the filtering criterion. Furthermore, this static dampening procedure is applied to all inventory items. Another global dampening procedure, suggested by Orlicky (1976) and Jackson (1974), is to implement all the rescheduling messages except for those generated within the minimum lead time. The minimum lead time, defined by Orlicky (1976), is the lead time required to complete an order under the highest priority.

Each dampening procedure currently used has its own strengths and weaknesses. These will be discussed in further detail in Chapter Three. In this research, a more comprehensive global dampening procedure is developed, and compared with the existing procedures under various production conditions. This dampening procedure evaluates rescheduling messages based on the cost tradeoffs of rescheduling. That is, each rescheduling message generated must be economically justified before it is implemented. Therefore, this model is designed to incorporate more job-related information than those currently in use.

Research Problem Defined

The major purpose of this research is (1) to investigate system nervousness, (2) to identify and classify several commonly used global dampening procedure, (3) to develop a cost-based global dampening procedure which incorporates more job-related information than the existing global dampening procedures, and (4) to evaluate the effectiveness of alternative global dampening procedures to cope with MRP system nervousness. Total related cost is used to measure the effectiveness of these dampening procedures. Several secondary performance measures, such as finished goods tardiness and inventory carrying cost, are also collected in order to explain unusual simulation results which do not conform to the normal expectation.

The importance of an MRP system's rescheduling capability is discussed in this research. There is little doubt that it is necessary to maintain up-to-date priority integrity on the shop floor. However, when the adverse effects of MRP system nervousness arise, corrective actions should be taken. Conventionally, safety stock, safety lead time, and safety capacity are the methods proposed to protect a production system against uncertainty (Melnyk, 1980; Milwaukee Chapter, Inc., 1977; New, 1975; Schmitt, 1984; Whybark & William, 1976). This research focuses on the use of information manipulation to deal with uncertain situations which exist within or outside the production system. The study is aimed at achieving the following specific objectives:

1. Describe and analyze system nervousness conceptually and operationally within an MRP context.

2. Evaluate the strengths and weaknesses of alternative global dampening procedures, and provide suggestions for their improvement.

3. Develop a more comprehensive cost-based dampening procedure and compare it with existing global dampening procedures, in terms of the total related cost.

Importance of the Problem

The development of MRP systems in the last two decades is a major breakthrough in production scheduling and inventory control. With the advancement of relatively inexpensive computing power of new-generation computer systems, MRP systems become a very effective tool in production. However, due to their complexity which is reflected by the interactions between MRP systems and other production subsystems, one of the operational problems, system nervousness, tends to hinder the successful implementation of this tool.

Both practitioners and academicians recognized the severe consequence of handling rescheduling problem inadequately. Mather (1977) proposed an approach to eliminating the causes of MRP system nervousness. However, this approach fails to eliminate some uncontrollable causes of system nervousness, such as MPS changes, that is the major concern of this study. Finally, the dampening procedures suggested in the literature have their own problems to deal with system nervousness effectively, which will be discussed in Chapter Three. The importance of this research project can be discussed in the following aspects.

Results of handling rescheduling problem inadequately

Serious problems arise when the number of rescheduling messages increase beyond the capability of planners to deal with them. If planners choose to ignore excessive rescheduling messages, they may need to resolve the resultant problems by chasing shortages, multiple set-up on the same job, or overtime in the plant (Carlson, 1980, p. 177). In this case, an informal system replaces the formal system that MRP strives to establish. In turn, this could lead to the total collaspe of an MRP system (Orlicky, 1975a, p. 40). Campbell (1971) summarized the adverse effects of rescheduling mishandling as considerably higher rescheduling costs, fluctuating capacity utilization, and confusion on the shop floor.

Inability of system nervousness elimination approach to resolving rescheduling problem satisfactorily

The causes of MRP system nervousness have been identified as MPS change, vendor/fall-down, scrap/spoilage, lot-size changes, safety stock changes, engineering changes, record errors, and unplanned transactions (Mather, 1977, pp. 64-69). Among the causes identified, some causes can be controlled to a certain degree (such as MPS changes, engineering changes and record errors). Others, such as vendor/plant fall-down and unplanned transactions, are uncontrollable in the short run.

Mather (1977) suggested an approach which seeks to reduce the number of rescheduling messages by attacking the controllable causes of system nervousness. To eliminate such causes as lot-size changes and safety stock changes, however, may adversely affect other costs. Furthermore, Mather's approach is not sufficient to deal with the uncontrollable causes of system nervousness. Therefore, a tradeoff analysis of schedule-changing cost and other affected cost is required to provide a means of economically justifying schedule changes.

Inadequacies of local and global dampening procedures

System nervousness or scheduling instability has been a concern of both practitioners and academicians (Campbell, 1971; Carlson et al., 1979; Erhorn, 1981; Fenton et al., 1975; Forrester, 1976; Graves, 1981; Huge, 1978; Kropp et al., 1979; Mather, 1977; Penlesky, 1982; Smith, 1978; Steele, 1975). Thus, there is no apparent lack of dampening procedures to reduce system nervousness. Firm planned orders, pegged requirements, lead time compression, time fencing, and automatic rescheduling are aimed at resolving rescheduling problem. Local dampening procedures limit the scope of unplanned events they attempt to resolve.

Existing global dampening procedures are rather simplified, and fail to incorporate some significant information, such as cost of rescheduling, to establish filtering criteria. The major reason for this research is to construct a more comprehensive global dampening procedure to aid decision-makers in dealing with rescheduling problems.

Research Methodology

A computer simulation model of a hypothetical, multiproduct and multistage factory, developed by Melnyk (1980), was used as the experimental vehicle for this research. Melnyk's simulated factory is based on the FACTRY simulation originally developed by Winters, with details relating to parts fabrication taken from the NATCO job shop. This factory has a final assembly line, a subassembly line, a job shop consisting of 10 work centers and 44 machines for parts fabrication, and a purchasing department. There are 15 products, 7 subassemblies, 15 parts, and 8 raw materials. Furthermore, there are a number of operating rules which make this simulated factory quite realistic.

Several revisions in this factory were required to adapt it to achieving the stated objective of this research. First, a rescheduling logic was developed for the MRP system used in the simulated factory. This logic is capable of generating the rescheduling messages in response to the occurrence of unexpected events. This modification pertains also to the cost estimations for rescheduling and not rescheduling, which are vital for the cost-based dampening procedure.

Since a regenerative MRP system was used in this study, any uncertainty within the production system, such as changes in the MPS or scrap problems on the shop floor, is only reported and reacted to at the time of MRP replanning. Through the explosion of the MPS along with the report of out-of-bound situations, the MRP system generates rescheduling messages. A global dampening procedure is then applied to filter these messages. The production system implements the significant rescheduling messages that come through the dampening filters. An appropriate action is taken to modify the open orders to be rescheduled.

Data are collected through the batch sampling of the multi-year simulation runs of this factory, under various operating conditions, which are controlled by the experimental design. The experimental factors include alternative dampening procedures, different uncertainty levels, capacity utilization levels, and lot-sizing rules.

The statistical techniques used in analyzing the simulation results are analysis of variance (ANOVA) and multiple pairwise comparison. ANOVA was basically used to analyze the effect of independent variables on the system performance measures. In this study, the F-test was used to determine whether the main effects and interaction effects among the production design factors are significant. In particular, the major emphasis is placed on comparing the effectiveness of the proposed cost-based dampening procedure with that of other dampening procedures.

Order of Presentation

In order to present this research and its results, this dissertation is divided into seven chapters. In the first chapter, a brief description of MRP system nervousness and dampening procedures is presented. Also, the objectives and significance of this research are discussed. The second chapter reviews the literature concerning MRP system nervousness, uncertainty buffering techniques, and local and global dampening procedures. The purpose of this chapter is to document the rescheduling problem that has been recognized by both practitioners and academicians, but has not been satisfactorily resolved.

In Chapter Three, the dampening procedures suggested in the literature are evaluated in further detail along with suggested improvements in these procedures. This chapter will also present a comparison of these dampening procedures with the more comprehensive dampening procedure developed in this research. The research objectives are defined in this chapter. The justification for selecting experimental factors is discussed in detail. Hypotheses to be tested are also included.

Chapters Four and Five present the research methodology used in this research. In Chapter Four, Melnyk's simulated factory along with the necessary revisions are described. The experimental design is examined, and statistical methods used to analyze the simulation results are discussed in Chapter Five.

Chapter Six reports the results of simulation study and the research hypotheses are evaluated. Finally, Chapter Seven discusses the implication of the simulation results and provides some guidelines for users in dealing with rescheduling problems. Suggestions for future study are also presented.

CHAPTER TWO

LITERATURE REVIEW

Within MRP system, production uncertainty can generally be resolved by two approaches, the use of rescheduling capability and the use of "slack". The rescheduling capability found in MRP systems is needed to maintain priority integrity by issuing rescheduling messages to realign the due date with the need date. However, when the number of rescheduling messages is beyond the capability of production system to respond, the rescheduling problem arises.

The rescheduling problem of the MRP system has gradually attracted greater attention from both practitioners and researchers (Campbell, 1971; Carlson et al. 1979; Graves, 1981; Mather, 1977; Penlesky, 1982; Steele, 1975). It can be said that MRP system nervousness is the reflection of the degree of uncertainty that exists within or outside the production system. In response to this problem, practitioners have proposed several dampening procedures to deal with uncertainty. The major objective of this research is to investigate the relative performance of alternative global dampening procedures to cope with MRP system nervousness under a broad range of operating conditions.

The second approach to dealing with production uncertainty is the use of "slack". Safety stock, safety lead time, and safety capacity are conventionally used "slack" to buffer the production system against uncertainty (Whybark and Williams, 1976). However, it is costly to use these traditional buffering techniques (Orlicky, 1976a). In order not to confound the impact of dampening procedures, these traditional buffering techniques are excluded in this experimental study.

This chapter begins by reviewing the literature regarding production uncertainty. Several traditional uncertainty buffering techniques are then discussed. Various definitions of MRP system nervousness are provided. Several local dampening procedures are reviewed, with particular attention to their applicability under specific situations. Finally, global dampening procedures are reviewed.

MRP System Under Uncertainty

The MRP system is a highly coordinated information system which reflects all changes in the production subsystems with which it interacts. The problem created by uncertainty, within or outside the production system for the operation of MRP systems, has been widely recognized (Garwood, 1971; Huge, 1978; Melnyk, 1980; Schmitt, 1984; Whybark and Williams, 1976). Whybark and Williams (1976) suggested categorization of uncertainty according to supply or demand uncertainty. Supply uncertainty represents changes in scheduled receipts, and demand uncertainty refers to changes in gross requirements. These two types of uncertainty can be further divided into changes in timing or quantity, which represent the dynamics in the real-world system. In this dissertation, both timing and quantity changes in the MPS will be considered.

Garwood (1971), Huge (1978) and Melnyk (1980) all have indicated that errors in lead time estimation are another source of production uncertainty. If lead times are consistently underestimated, there will be a large number of past-due orders on the shop floor, and rescheduling to later dates is then required. When end items cannot be completed on time, the validity of the MPS is then affected.

Mather (1977) recommended that controllable causes be eliminated to allow material planners sufficient time to deal with the remaining significant rescheduling messages. However, even in an "ideal" production system, in which all the controllable causes of uncertainty are eliminated, material planners will still need to resolve problems of unplanned events. The present study will address these uncontrollable causes of system nervousness.

Another way to classify uncertainty, in addition to the categorization schemes already mentioned, is to identify uncertainty as either internal or external. Internal uncertainty, or system uncertainty, is defined as the result of unexpected events that occur within the production system: machine breakdowns, equipment malfunctions, and scrap problems are typical examples. External uncertainty exists beyond the production system, and includes such factors as purchasing lead time fluctuation, and demand uncertainty. The present study is focused on the MPS changes due to demand uncertainty. Scrap problems which represent system uncertainty are also investigated in this study.

Traditional Uncertainty Buffering Techniques

Several alternatives are available to protect the production system against uncertainty. These traditional uncertainty buffering techniques rely on the "slack" to protect the system against uncertainty.

<u>Safety stock</u>

Conventionally, safety stock is the method most frequently mentioned for dealing with quantity uncertainty (Blackburn and Mellon, 1982; Carlson et al., 1979; Erhorn, 1981; Fenton et al., 1975; Huge, 1978; Liaw, 1979; Ling, 1974; New, 1975). Before the advent of MRP systems, safety stock was maintained at every level of product structure. The use of traditional inventory control systems, such as the order point system, resulted in waste in the form of excessive work-in-process inventory and in deteriorating customer service level. According to Orlicky (1975a), the importance of safety stock has been diminishing, and it should be used only to compensate for forecast errors at the end-time level. Orlicky (1975a) also has illustrated the inapplicability of traditional statistical techniques in establishing the amount of safety stock to keep on hand.

Berry and Whybark (1975) examined a widely suggested method of maintaining safety stock: only at the end-item level and the raw-material level. However, after testing this generally accepted perception in terms of several performance measures under various cost structures and degrees of uncertainty, Liaw (1979) concluded that the determination of where safety stock should be maintained depends upon the inventory risk involved at each level. New (1975) implied that safety stock can be effective for buffering quantity change. In studying a single-stage process, Whybark and Williams (1976) also concluded that maintaining safety stock is the preferred technique under conditions of quantity uncertainty.

Safety lead time

Safety lead time is another inventory oriented buffering technique, which provides similar buffering as safety stock (Whybark & Williams, 1976). The basic principle in applying the safety lead time technique is to have components, subassemblies, or assemblies in stock before the dates of actual need. However, there is a tradeoff when using safety lead time as an uncertainty buffering technique. As with safety stock, this method requires an extra financial investment for carrying inventory over the length of the safety lead time. The determination of the amount of safety lead time is made by seeking a balance between the value of the buffering provided and the inventory investment (Huge, 1978; Huge, 1979).

New (1975) suggested that safety lead time be valuable for purchased items, for they are subject to variability in vendor production and transportation time. Whybark and Williams (1976) also concluded that the use of safety lead time is preferred under conditions of timing uncertainty.

Some reseachers indicated that the provision of safety lead time produces better system performance. The guideline of lead time estimation suggested by Melnyk (1980) included the appropriate use of safety lead time. Kanet (1980) found that manufacturing lead time can be estimated by assigning allowance for the flow of the job through the shop floor. Those practitioners who favor short manufacturing lead time seem to imply that safety lead time is not an adequate buffering technique (Huge, 1979; Orlicky, 1975a; Wight, 1974). Wight (1974) strongly opposed lengthening lead time in response to a large number of past due orders; the actual reason for the problem, he asserted, is lack of capacity. Therefore, there is still a gap between researchers and practitioners in their perception of the value of safety lead time.

Safety capacity

Safety capacity, although rarely used, is another method for handling production uncertainty (Milwaukee Chapter, Inc., 1977; Whybark and Williams, 1976). Without a doubt, rescheduling problems are much easier to resolve when there is slack capacity. With safety capacity, a certain percentage of production capacity is reserved to accommodate last-minute rush orders and changes (Carter & Monczka, 1976). However, if such emergency orders are not needed, this method can be very costly. It should be noted that safety capacity is applicable when dealing with bottleneck work centers. However, these are the work centers that need to be carefully scheduled based on the amount of capacity available. Due to this dilemma, safety capacity is seldom reserved intentionally in the typical industrial practice (Milwaukee Chapter, Inc., 1977).

Summary of uncertainty buffering techniques

In this section, the adverse effects of using uncertainty buffering techniques are briefly discussed. The major flaws of these buffering techniques are lack of clear guidelines regarding when to use them, and severe disadvantages in carrying extra inventory. Furthermore, exploring the effectiveness of using these techniques to buffer against uncertainty is beyond the scope of this thesis. Thus, all these buffering techniques are not included in this study. However, in the last chapter, this study will propose a future research direction that compares the performance of these traditional uncertainty buffering techniques with that of MRP system's rescheduling capability.

In this research, uncertain events are handled by an important function of MRP system, rescheduling capability. This rescheduling capability is based on the assumption that "the lead time compression approach is capable of accomodating any MPS change that has passed down to the lower levels" (Berry & Whybark, 1975, p. 22). After a certain point, system flexibility is unable to absorb all the scheduling changes, so dampening procedures should be considered. This study is focused on this information manipulation approach to dealing with production uncertainty.

MRP System Nervousness

Rescheduling is an important operational problem for MRP systems and is recognized by researchers and practitioners alike (Campbell, 1971; Carlson et al., 1979; Erhorn, 1981; Fenton et al., 1975; Forrester, 1976; Graves, 1981; Huge, 1978; Kropp et al., 1979; Mather, 1977; Penlesky, 1982; Schmitt, 1984; Smith, 1978; Steele, 1975). MRP system nervousness generally refers to the frequent rescheduling of open orders that is beyond the capability of a production system to handle. Mather (1977) presented a comprehensive list of the causes of MRP system nervousness: MPS changes, vendor/plant fall-down, scrap/spoilage, lot-sizing changes, safety stock changes, engineering changes, record errors, and unplanned transactions. Carlson (1980) maintained that system nervousness will result from any failure to correct an out-of-bounds situation, such as machine breakdowns.

The negative effects of system nervousness are summarized as considerably higher rescheduling cost incurred, fluctuation in capacity utilization, and confusion on the shop floor (Campbell, 1971). It should be noted that these negative effects are not the direct results of MRP system nervousness. System nervousness simply reflects the level of uncertainty exists in the production system. That is, when an uncertain event occurs, an MRP system must be adjusted through its rescheduling capability. After a certain point, the large number of rescheduling messages do not allow production system to respond in a timely fashion, and the problem of implementing rescheduling notices arises.

Dampening procedures are one of the methods to deal with MRP system nervousness. This method suppresses insignificant rescheduling messages to allow MRP planners to concentrate on the significant rescheduling messages. In so doing, the priority integrity may be interrupted temporarily due to the suppression of insignificant rescheduling messages. Therefore, a dampening procedure can be viewed as a compromise between maintaining valid priorities provided by the MRP system's rescheduling capability and minimizing the adverse effects of system nervousness.

Dampening Procedures

In general, a dampening procedure refers to the filtering process which screens out "insignificant" rescheduling messages. The insignificant rescheduling messages are considered as having less negative impact on the system performance if they are suppressed. The significant rescheduling messages, in contrast, have an important effect on system performance that should be implemented immediately.

Due to various criteria used to determine insignificant rescheduling messages, the dampening procedure can be divided into "local" and "global". In this study, global dampening procedures can be defined as the procedures designed to deal with any type of unplanned events occurred in the production system; local dampening procedures are designed to resolve a specific type of uncertainty. Local dampening procedures can be further classified by the level in the product structure, and the nature (timing or quantity) of uncertainty. Whybark and Williams' (1976) taxonomy of MRP system uncertainty helps to establish a framework for analyzing dampening procedures, as shown in Figure 2.1. This framework provides a means for evaluating the appropriateness of each dampening procedure applied to each type of uncertainty. Each local dampening procedure is discussed below.

Demand/MPS management

The objective of using this technique is to stablize the MPS when there are only slight changes (in terms of quantity, timing, or both) in customer orders (Carlson, 1980, p. 179). Dippold (1975) and Forrester (1976) have noted the importance of having a stable MPS in order to drive an MRP system effectively. A step toward achieving this stability is to make sure that the MPS is realistic and feasible (Stevens, 1977, p. 123); that is, rough-cut capacity planning is applied at the end item level. An overloaded MPS not only is incapable of handling emergency changes, but also is inclined to build up a large quantity of past-due orders. Leo (1975) outlined a comprehensive approach to establish a realistic MPS through rough-cut capacity planning. This was also advocated by other practitioners and academicians (Hershauer, 1978; Smolens, 1977; Vollmann, 1973).

	Timing	Quantity
End item level in the product structure	.Demand Management .Time Fencing	.Demand Management .Time Fencing
Component level in the product structure	.Lead Time Compression	.Pegged Requirements

Figure 2.1 Classification Framework of Local Dampening Procedures

Pegged-requirements/firm planned order

A firm planned order (FPO) is defined as a planned-order that cannot be adjusted automatically by computer (Orlicky, 1975b, p. 58; Mather, 1977, p. 77). In the present study, an FPO is viewed as a kind of system command, not an individual dampening procedure. By itself, FPO cannot achieve the objective of dampening MRP system nervousness because FPO only firms up an open order at a certain time period and prevents it from moving to another time period during the next replanning. Therefore, FPO should be used with some other local dampening procedure (such as pegged requirements, lead time compression, or time fencing) in order to resolve rescheduling problems.

Orlicky (1975b), Mather (1977), and Steele (1975) suggested using a combined pegged requirements/firm planned orders approach to resolving rescheduling problems at the component level by splitting the lot size of the parent item. Basically, the pegged-requirements technique is used to handle the quantity uncertainty, especially when a coverage problem is caused by the lot-sizing rule.

An example shows how this pegged-requirements technique resolves an unplanned event. In Figure 2.2, gross requirements for Item Y in Week 4 increase from 13 to 20. After lead time offsetting, 25 units of Y must be released immediately which will be needed in 3 weeks. If the pegged-requirements technique is used to resolve this coverage problem, the parent item, X, is found. It is obvious that the problem actually results from the lot-sizing rule of the parent item. In Figure 2.3, it is shown that the planned-order release for X in Week 4 can be reduced to 13, covering two periods' net requirements. Eighteen units of Item Y can then be released without expediting.

Lead time: 2 weeks		Week 1	2	3	4	5	6	7	8
Gross Requirements		10	5	8		12	10	8	7
Scheduled Receipts									
On Hand	40	30	25	17	17	5	-5	-13	-20
Planned Order Releases					20			18	

Item X

Lead time: 5 weeks		Week 1	2	3	4	5	6	7	8
Gross Requirements					20			18	
Scheduled Receipts					8				
On Hand	5	5	5	5	-7	-7	-7	-25	-25
Planned Order Releases		25							

Item Y

Figure 2.2 Problem of Coverage

Lead time: 2 weeks

		Week							
		1	2	3	4	5	6	7	8
Gross Requirements		10	5	8		12	10	8	7
Scheduled Receipts									
On Hand	40	30	25	17	17	5	-5	-13	-20
Planned Order Releases					13		18		

Item X

Lead time: 5 weeks

		Week							
		1	2	3	4	5	6	7	8
Gross Requirements					13		18		
Scheduled Receipts					8				
On Hand	5	5	5	5	0	0	-18	-18	-18
Planned Order Releases		18							

Item Y

Figure 2.3 Application of Pegged Requirements Technique

It should be noted that the pegged-requirements technique is simply an information retrieval method. It must be accompanied by lot-splitting technique to achieve the purpose of eliminating an uncertainty problem. Then, a firm planned order is applied to assure the split lot would not be combined in the next MRP replanning.

The pegged-requirements technique provides the capability to trace the gross requirement of the component item to its sources (Orlicky, 1977, p. 162). In terms of tracing capability, it is necessary to differentiate between single-level pegging and full pegging. Single-level pegging provides the capability to trace the source of item demand only to its immediate parent level, while full pegging can trace up to the master-schedule level. Orlicky (1975b), Peterson (1975), and Wemmerlov (1977) all opposed use of full pegging because other MRP design factors, such as lot sizing, safety stock, and scrap allowance, tend to obscure a clean path of upward tracability.

Lead time compression/firm planned order

Lead time compression can be defined as the reduction of the normal planned lead time in response to an unplanned event to a shorter desired lead time through a FPO. It is important to distinguish between traditional expediting and lead time compression. Traditional expediting is part of the informal scheduling system that the MRP system strives to replace. Traditional informal expediting usually relies upon the subjective judgment of shop floor foremen or expeditors. Lead time compression, on the other hand, can be viewed as "formal expediting" initiated by rescheduling messages generated by the MRP system. Informal expediting, on the other hand, is initiated by some subjective judgment of shop foremen, and not by the formal system.

Mather (1977) and Jackson (1974) suggested using lead time compression with FPOs to tackle production uncertainty. A recent research survey by Mognaddam (1981) reported that lead time compression techniques are frequently used to manage manufacturing lead time. Several alternative techniques for lead time compression are discussed below (IBM, 1972, Chapter 6, p. 31).

1. Queue time management

Plossl and Wight (1967) indicated that manufacturing lead time consists of set-up time, running time, queue time, move time, and wait time. Queue time is said to be about 90 percent of manufacturing lead time (Orlicky, 1975a, p. 259); therefore, it can be most effective to reduce the amount of time that an order spends in the queue.

2. Order overlapping and operation splitting

Order overlapping means allowing the next operation required by an order to start before previous operation has been completed on the entire lot (IBM, 1972, Chapter 6, pp. 27-28). This process can also be employed to relieve congestion at a work center, to utilize idle capacity, or to ensure that the next operation can begin without delay (IBM, 1972, Chapter 6, p. 27).

Operation splitting means performing one job in parallel on two or more machines or assigning several persons to the same job (IBM, 1972, Chapter 6, p. 28). This expediting procedure is usually expensive because multiple setups may be required.

3. Lot splitting

This technique can be used when run time is significant part of manufacturing lead time. Lot splitting means reducing lot size and running these small lots on several machines in order to reduce manufacturing lead time.

Time fencing/firm planned order

The terminology used in referring to time fencing or time freezing is far from standard. Time fences are generally defined as "policies or guidelines established to note where various restrictions or changes in operating procedures take place" (Proud, 1981, p. 61). Two completely different uses of time fencing depend upon the user's perception about automatic rescheduling. Proud (1981) and Schwendinger (1978) defined the two time fences: planning time fence (PTF) and demand time fence (DTF). Forrester (1978) used different terms for similar concepts: firm order periods and firm planned order periods. PTF is "the number of periods from the beginning of the planning horizon in which the master schedule will not be altered by the system" (Proud, 1981, p. 62). That is, any rescheduling message generated within the PTF is subject to analysis by the master scheduler.

DTF is defined as "the number of periods from the beginning of the planning horizon where availability will be calculated using actual demand instead of forecast" (Proud, 1981, p. 62). DTF delineates the plant's final commitment to the schedule within which almost no rescheduling at the MPS level will be accepted, or only according to very strict rules. For instance, engineering changes must first be carefully analyzed; an emergency customer order must be approved by the president of the company.

Obviously, the purpose of using time fences is to determine the point at which the planners must seize control of the MPS. Automatic rescheduling within the PTF is considered unacceptable. Proud (1980) suggested that the ideal place to establish the PTF is in the cumulative lead time (CLT), while the DTF is generally established for final assembly lead time (Proud, 1980, p. 414). Figure 2.4 shows how these time fences are established.

Application of local dampening procedures

From the foregoing discussion of local dampening procedures, it can be seen that they are designed to deal with a specific type of production uncertainty, and, in turn, reduce the number of rescheduling messages. These local dampening procedures can be built in MRP explosion logic, and thus can be viewed as "corrective actions." For instance, the use of lead time compression can certainly eliminate the rescheduling messages for all the lower level items affected. A sophisticated MRP system may incorporate all the local dampening procedures described. The major objective of the present study is to evaluate the effectiveness of global dampening procedures. In order to keep the effect of a given global dampening procedure unconfounded by the incorporation of these local dampening procedures in the MRP system, a simple regenerative MRP system without any built-in local dampening procedure is used.

Global Dampening Procedure

A global dampening procedure can be defined as a set of heuristic rules used to address any type of production uncertainty. The objective

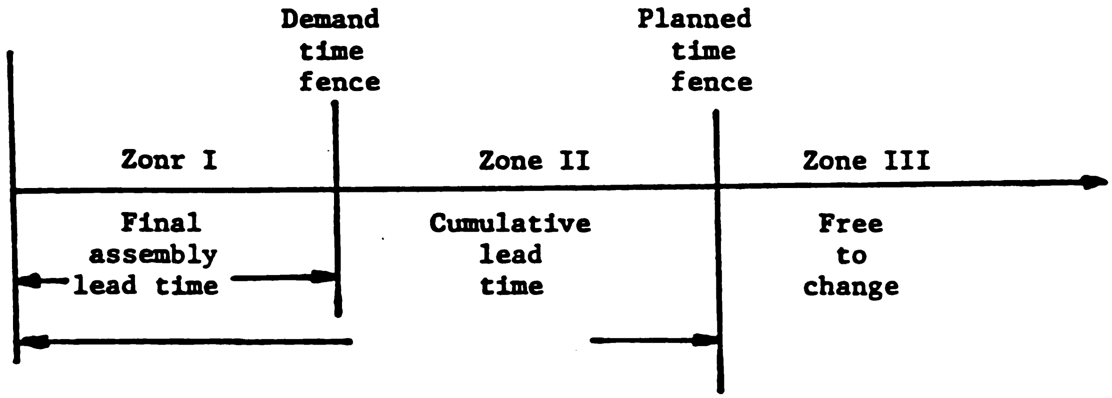


Figure 2.4 Establishment of Time Fences

of the global dampening procedure is to reduce the number of rescheduling notices to be implemented. Dampening logic varies so widely that a classification scheme is required for analysis purpose. The currently available global dampening procedures can be roughly divided into static dampening procedures and automatic rescheduling procedures. The former refers to a set of heuristic rules that are rarely changed after they are installed and are usually applied to all the items. The latter recognizes the significance of the MRP's rescheduling capability, and attempts to implement all the feasible rescheduling messages for shop orders.

Static dampening procedure

Mather (1977) suggested that planners ignore any reschedule-in message of only one week and any reshedule-out less than two weeks. A "no rescheduling fence" is established around the original due date to classify timing change type of rescheduling messages. A reschedule-in of "a" weeks, or reschedule-out of less than "b" weeks, is to be ignored.

This static dampening procedure can also be appied in rescheduling purchase orders. Wemmerlov (1979) reported that some companies he surveyed neglect updated information, and thus do not inform vendors each time a new schedule is produced; other companies, with net change MRP systems and daily runs, print only rescheduling messages or actual reschedulings, once a week, and only for purchase orders. Fenton et al. (1975) suggested that the purchase order be treated very much the same as the shop order. The single exception is that a revised due date must differ from the original due date by more than two weeks before action is taken.

Automatic Rescheduling Procedure

An automatic rescheduling procedure was suggested by Orlicky (1976) and Jackson (1976) to relieve planners of the burden of handling rescheduling problems. Orlicky (1976) and Jackson (1974) proposed a general rule that all released shop and assembly orders should be automatically rescheduled as the MRP system recommends (Jackson, 1974, p. 222). The only exception is that no rescheduling should be allowed within the minimum lead time. Furthermore, Jackson (1974) indicated that there are only a few reasons why shop orders should not be automatically rescheduled by computer. The following are some of his proposed rules:

1. Never reschedule an order into a past due period.

2. Do not reschedule it further past due when the due date of the order is already past due.

3. Do not try to split the order by computer to reschedule part of it to a later date (Jackson, 1974, p. 222).

As for rescheduling problems with purchase orders, Jackson (1974) suggested establishing a "drop dead fence" and a "no rescheduling fence." The former is the shortest time agreed to by the vendor for acceptance of a schedule-change notice. The latter defines a point of time beyond which no rescheduling by computer is implemented (Jackson, 1974, p. 222-223). Orlicky (1976) proposed an earliest due date and a rescheduling time fence which are similar to Jackson's time fences for purchase orders. Figure 2.5 illustrates these two treatments of purchase orders.

Finally, Orlicky (1976) provided insight into dampening procedures for purchase orders. A weekly update of purchase requirements for all

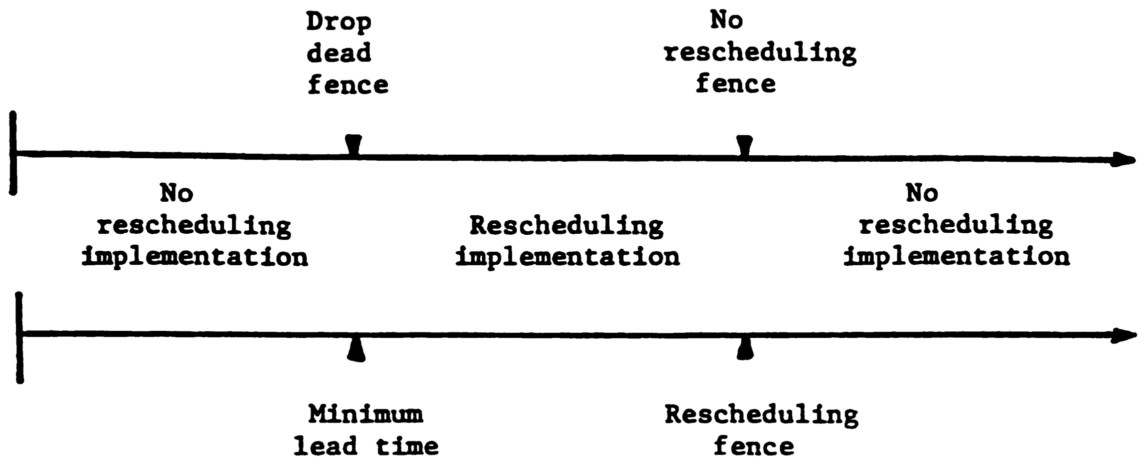


Figure 2.5   Two Types of Rescheduling Fence

orders placed with a given vendor is prepared, and revisions of desired delivery dates provide a basis for negotiation. Orlicky listed some decision criteria for determining whether or not a rescheduling message is trivial:

1. Magnitude of divergence (the difference between date of need and due date)

2. Direction of date-of-need change (needed earlier or later)

3. Distance in time (how far in the future) (1976, p. 44).

Based on these criteria, some general principles were suggested: "the need for rescheduling to an earlier date is more significant than a later date, and action on which can be delayed or even ignored. Change to an earlier date is more significant the closer it is to the current date" (Orlicky, 1976, p. 45). A "test of significance" is then proposed to determine whether a rescheduling decision should be implemented, based on the three criteria listed above (Orlicky, 1976, p. 45).

Related Research

Penlesky (1982) conducted the first systematic research on open order rescheduling. In his study, the effectiveness of two dampening procedures, dynamic and static dampening procedure, are investigated via a five-factor (rescheduling procedure, MPS uncertainty level, machine utilization level, planned lead time and lot size) experimental design. However, the static rescheduling procedure used in his study is simply a "no rescheduling procedure". That is, no rescheduling would be implemented once the due dates are determined. Dynamic dampening procedure is to implement every rescheduling message generated. Therefore, it can be viewed as a "no dampening procedure".

Penlesky (1982) also studied four rescheduling heuristics, originally suggested by Orlicky (1976), Jackson (1974), Mather (1977), and Peterson (1975), in one particular operating condition. Ability heuristic is based on Orlicky's (1976) concept of minimum lead time to determine the feasibility of a rescheduling message. Magnitude heuristic follows the suggestions made by Mather (1977) to establish a "no rescheduling fence" to screen out the rescheduling messages with minor changes. Horizontal heuristic is derived from one component in Orlicky's (1976) "test of significance" discussed previously for purchase orders, distance in time. That is, the rescheduling messages generated in the near future should be implemented while those generated in the distant future may be ignored. Finally, Orlicky's heuristic is the hybrid of magnitude and horizon heuristic, which considers the ratio between the magnitude of schedule change and distance in time.

The major conclusion of Penlesky's (1982) study is that the "no rescheduling procedure" is inferior to "no dampening procedure", and to any other rescheduling heuristics under any operating condition considered in his study. He also concluded that there is no statistically significant difference between the four rescheduling heuristics tested.

Another contribution of Penlesky's (1982) study is that the behavioral effects of MRP system nervousness is first exploited systematically in addition to its operational effects. The major behavioral effect is that the large number of rescheduling messages generated by the MRP system can inundate production planners so that planners cannot evaluate all the rescheduling messages in a timely basis (Penlesky, 1982, p. 7). One solution to this problem is to hire more planners, which only camouflages the problem. Penlesky summarized the behavioral complications that may arise as a result of the failure of planners to perform their jos as follows:

1. The production planner simply stops trying to perform an important task.

2. The individuals in the shop lose faith in the due date oriented priority planning system and initiate a variety of informal prioriity planning systems.

3. Ill-chosen or randomly chosen rescheduling messages are communicated to the shop to be used in scheduling operations.

However, Penlesky's research only investigated timing uncertainty in the MPS. Both timing and quantity uncertainty in the MPS, along with scrap problems, are included in this study. Furthermore, these four rescheduling heuristic discussed are rather simplistic, although they are intuitively sound. As Penlesky suggested, other information, such as the cost-related information, can be used in the development of a more sophisticated dampening procedures. The thesis intends to study the effect of including the cost-related information on the open order rescheduling.

Summary of Chapter Two

In this chapter, MRP system nervousness was fully discussed. It is important to recognize the relationship between uncertainty and MRP system nervousness. System nervousness is the symptom of production uncertainty. Three conventional uncertainty buffering techniques are also reviewed in terms of their strengths and weaknesses. Although they are the alternatives to rescheduling capability to deal with production uncertainty, this research does not intend to evaluate their effectiveness against that of rescheduling capability of MRP systems.

Both local and global dampening procedures were reviewed in detail. Finally, a related research conducted by Penlesky (1982) was also reviewed. The differences between Penlesky's research and the current study were pointed out. In the next chapter, two existing global dampening procedures, (the static dampening procedure and the automatic rescheduling procedure), will be evaluated further, along with the suggestions for improvements upon them. In an attempt to improve the preformance of dampening procedures, a cost-based dampening procedure will then be described in detail.

CHAPTER THREE

RESEARCH FRAMEWORK FOR DAMPENING PROCEDURES

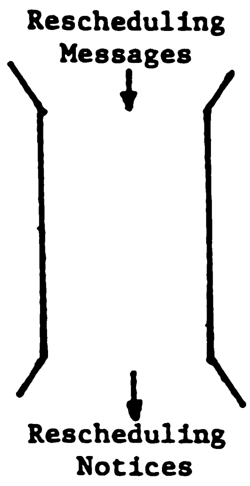
The major purpose for using dampening procedures in an MRP system is to help decision-makers classify rescheduling messages and identify rescheduling notices that should be implemented. The establishment of dampening procedures can be very subjective. For instance, the parameters used to establish the "no rescheduling fence" for the static dampening procedure is generally based on the subjective judgment of MRP planners. In the automatic rescheduling procedure, the minimum lead time used to determine the feasibility of a rescheduling message may be defined differently from one MRP user to another. Thus, the dampening criterion used certainly affects the number of rescheduling messages filtered, which in turn may have a significant impact on the overall performance of the production system.

This research project reviews the existing dampening procedures, which are described in the previous chapter. This study focuses on global dampening procedures because local dampening procedures deal with a limited scope of production uncertainty. As a result, local dampening procedures are not included in the simulation experiment. Therefore, the term of "dampening procedure" is meant to represent global dampening procedure for the rest of the thesis. One objective of this thesis is to evaluate the relative performance of alternative dampening procedures to cope with MRP system nervousness. In this chapter, a research framework for studying these dampening procedures will be provided. The static dampening procedure and the automatic rescheduling procedure will then be evaluated in terms of their strengths and weaknesses. Then, the cost-based dampening procedure will be described in detail. Finally, the research objectives of this study will be defined.

Conceptual Framework

The concept of filtering can be used to explain the function of a global dampening procedure (Figure 3.1.) Each dampening procedure is designed to screen out insignificant rescheduling messages, based on various criteria, such as the feasibility of implementing rescheduling messages and the magnitude of change. It should be recognized that the suppression of any rescheduling message will disrupt updating of the current priority status of open orders. However, this temporary disruption can be expected to have little negative impact on the system performance if the dampening procedure is well designed. For instance, a delay in the early stage of production may be made up in a later stage of production. Another example is that the late penalty of an open order may be lower than the cost of rescheduling this order.

In this research, the effectiveness of a global dampening procedure is measured in terms of the overall performance of the production system as measured by the total related cost. Several secondary perfomance measures, such as inventory carrying cost and finished goods tardiness, are used to evaluate and explain unusual simulation results. The considerations in the selection of a global dampening procedure include understandability, implementability, and completeness. These factors



Dampening Criterion

.Static Dampening Procedure
.Automatic Rescheduling Procedure
.Cost-based Dampening Procedure

Figure 3.1 Dampening Filter

will be discussed in further detail as each dampening procedure is presented.

This research evaluates the strengths and weaknesses of two existing global dampening procedures. The cost-based dampening procedures developed in this research incorporates more information for decision-making than do other procedures.

The main thrust of this research is to use alternative dampening procedures to classify rescheduling messages into two groups: significant rescheduling messages, which need to be implemented immediately by revising due dates of open shop orders; and insignificant rescheduling messages, which can be ignored in the current period. In the discussion of the various dampening procedures, their mechanisms are introduced first, followed by evaluation of these procedures and then suggestions for improvement.

Static dampening procedure

In this study, the static dampening procedure is based loosely on the rules suggested by Mather (1977) and Peterson (1975). The basic concept behind this procedure depends upon system flexibility to accommodate minor out-of-bounds situations. System flexibility can be in the form of unused production capacity, overtime, or subcontracting. There is the implication of this dampening procedure that the cost of maintaining system flexibility can be ignored.

Mechanism

Mather (1977) proposed, as a rule, to ignore rescheduling-in messages of only one week and rescheduling-out messages of less than two weeks (p. 75). Figure 3.2 shows a "no rescheduling fence" around the old due date to classify rescheduling messages. The scale represents the magnitude of timing change in either direction. A reschedule-in of "a" weeks, or reschedule-out of less than "b" weeks, is to be ignored. It should be noted that "no rescheduling fence" is not necessarily symmetric. That is, the absolute values of a and b can be different because the importance of reschedule-in and reschedule-out may be perceived differently. Furthermore, the width of "no rescheduling fence" determines the behavior of this dampening procedure. When "no rescheduling fence" widens, the performance of static dampening procedure should converge to that of "no rescheduling procedure". That is, almost no rescheduling message would be implemented because of the width of "no rescheduling fence".

<u>Evaluation</u>

The basic assumption of this procedure is that each production system has a certain degree of flexibility for responding to the minor changes in order to keep the current schedule intact. The minor changes are the rescheduling messages generated within "no rescheduling fence". By ignoring minor scheduling changes, the production system may turn to short-term strategies, like overtime operation, to accommodate such changes. The establishment of a "no rescheduling fence" depends upon planners' perception of system flexibility in this subjective dampening procedure.

Although this subjective judgment will be replaced in this project by a conclusion derived from the results of several trial runs conducted to determine the values of "a" and "b", some pitfalls remain. The major

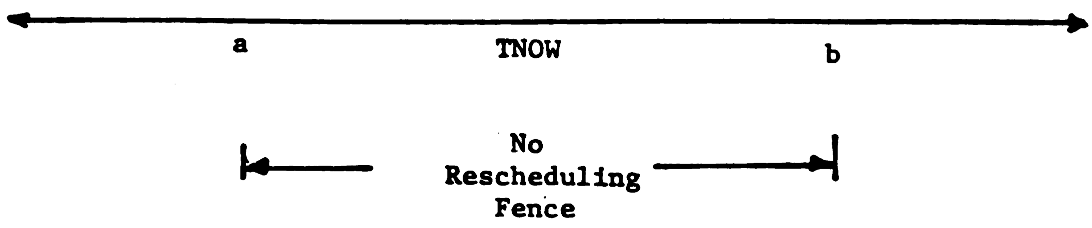


Figure 3.2 Static Dampening Procedure

weakness is that the criteria used to classify the rescheduling messages ignore some significant information, such as the cost trade-offs of rescheduling. As a consequence, the negative effects of MRP system nervousness--considerable rescheduling cost, fluctuating capacity utilization, and priority confusion on the shop floor--may not be substantially reduced. It is still possible that many rescheduled orders will be implemented during one period, while there are few orders during other periods. In such case, capacity utilization tends to fluctuate. The overtime premium paid during peak periods and the idle time cost during slack periods can be considered costs incurred due to inappropriate handling of rescheduling problems.

One potential weakness of this procedure is the static nature of the "no rescheduling fence". Once the rescheduling fence is defined, it is rarely revised, regardless of important changes that may occur. It would seem appropriate to periodically update these parameters. This could be done by tracing performance of this dampening procedure over time. However, this periodical update treatment of this procedure is beyond the scope of this research.

Another weakness of this procedure is its universal application to every part without regard to lead time, cost, and importance of each part. It is possible to establish a "no rescheduling fence" which is related to the lead time of an individual item. That is, the shorter the lead time, the narrower the "no rescheduling fence".

Nevertheless, this procedure is simple to use and easy to understand. It may work well for some MRP users, if system slack is used to establish a "no rescheduling fence" appropriately and if there are not many major changes in the system. Thus, the effectiveness of this dampening procedure mainly depends upon how accurately system flexibility or system slack is perceived by decision makers. By no means is this an easy task.

Automatic Rescheduling Procedure

Jackson (1974) and Orlicky (1976) are proponents of an automatic "rescheduling" procedure. They maintain that all rescheduling messages for shop orders which can be implemented (i.e., are feasible) are significant. This automatic rescheduling procedure is a form of "no dampening procedure". By definition, a "no dampening procedure" implements every rescheduling message generated by an MRP system irrespective of whether it is feasible or not. The automatic rescheduling procedure also implements all the rescheduling messages generated. The only difference between tha automatic rescheduling procedure and "no dampening procedure" is the treatment of the rescheduling messages generated within the minimum lead time. "No dampening procedure" will change the due date as suggested by the MRP system, while the automatic rescheduling procedure reschedules the due date of this open order to the date of minimum lead time. Thus, a "minimum lead time" needs to be established in order to prevent any order from being rescheduled inside of the time interval.

Jackson (1974) and Orlicky (1976) also maintained that shop orders and purchase orders should be treated differently. A request for changes in purchase order due dates is subject to negotiation and agreement by the vendor (Orlicky, 1976, p. 44). Since this study is only concerned with the rescheduling problem of shop orders, no difference in treatment between these two types of orders is applied in the research.

Mechanism

In the automatic rescheduling procedure, every feasible rescheduling message is to be implemented as requested. The only exception is the rescheduling messages generated within the minimum lead time. The concept of minimum lead time is very important in this procedure. In this research, an operating scheduling system on the shop floor is used to determine whether or not rescheduling messages are generated within the minimum lead time (Orlicky, 1976, p. 43). Minimum lead time in this research is computed as the sum of operation time plus set-up time for the remaining operations, plus any remaining operation time for processing the current order on the machine. This procedure tends to be concerned about evaluating reschedule-in situations. All reschedule-out messages will be implemented.

Evaluation

This dampening procedure assumes that the production system will be able to accommodate any emergency event, such as machine breakdown or scrap, unless rescheduled orders are moved within the minimum lead time. This assumption ignores the cost of rescheduling. The maintenance of up-to-date priorities is the major goal. Furthermore, this system overlooks capacity utilization. If many unexpected events occur at one time, and many rescheduling messages are generated, capacity utilization will fluctuate. Since this procedure is close to a "no dampening procedure", frequent changes in the priority of open orders can be expected. This production system can still be very nervous when this procedure is used.

Nevertheless, this procedure does have some advantages. First, this procedure is part-dependent. That is, the rescheduling logic is dependent upon the minimum lead time for an individual component. The procedure is also dynamic in nature. The determination of minimum lead time depends upon the current stage of operation. Another major advantage frequently mentioned by the proponents of automatic rescheduling is that it does relieve the burden on material planners to analyze all rescheduling messages generated (Jackson, 1974; Orlicky, 1976).

It should be noted that automatic rescheduling procedure and static dampening procedure are similar in their dependence upon system flexibility to accommodate unexpected changes (through such means as overtime, operation splitting, and subcontracting). The cost of maintaining system flexibility should somehow be recognized. Overtime premium costs, multiple set-ups, and subcontracting supervision can be very costly.

Cost-based dampening procedure

The major weakness of the two procedures just described is that they ignore the cost tradeoffs of rescheduling. Therefore, a dampening procedure based on the cost tradeoffs of rescheduling was developed in this study. The procedure tends to counteract the negative effects of MRP system nervousness while recognizing the importance of maintaining priority integrity.

Carlson et al. (1979) first proposed the inclusion of the "cost of nervousness" in lot-sizing rule to dampen MRP system nervousness. The cost of nervousness is the additional cost of disrupting previously established schedules (Carlson et al., 1979, p. 54). Then, inventory carrying cost, set-up cost, and cost of nervousness are used in the Wagner-Whitin lot-sizing algorithm to determine the least cost schedule. The major problem with their definition of cost of nervousness is that they are concerned about the changes of planned orders rather than open orders. Changes in planned orders have much less effect on the production system than that in open orders. Furthermore, the estimation of cost of nervousness proposed by Carlson et al. (1979) is rather simplistic. This study develops the cost estimation of rescheduling and not rescheduling which plays a major role in the cost-based dampening procedure.

Mechanism

In the cost-based dampening procedure, each rescheduling message must be economically justified. A comparison between the cost of rescheduling and the cost of not rescheduling is made. A rescheduling message is viewed as "cost effective" or "significant" if the cost of rescheduling is less than the cost of not rescheduling; otherwise, a rescheduling message is deemed as "insignificant," and will not be implemented.

Since estimation of the costs of rescheduling and not rescheduling is a vital part of this dampening procedure, a detailed discussion is warranted. The following situations that will be considered in the cost estimation.

1. Rescheduling-in messages

An example is presented in Figure 3.3 to illustrate cost estimation for rescheduling messages. For a certain machine, three jobs (#2, #3, and #4) are in the queue, and one job (#1) is being processed. After the shop foreman receives a rescheduling message to expedite Job #4, the priority of the jobs in the queue is recalculated based on the earliest due date job sequencing rule. Assuming that Job #4 has the highest priority after the recalculation of priority, the affected orders are Job #2 and Job #3. If they cannot be completed by their planned operation due dates, the cost of rescheduling, in this case, is the possible penalty for late completion of Job #2 and Job #3. The operation due date for each operation is determined by the following equations.

$$OPDD_1 = \text{Current date} + \frac{\text{Operation time of the first operation}}{\text{Total operation time}} * \text{Lead time}$$

$$OPDD_i = OPDD_{i-1} + \frac{\text{Operation time of the ith operation}}{\text{Total operation time}} * \text{Lead time}$$

where $OPDD_i$ represents the operation due date for the ith operation

The penalties for late jobs can be determined using a forward scheduling technique. For Job #2, the time required before completion of this job is the sum of remaining operation time for Job #1, and set-up and operation time for Job #4 and Job #2. An expected finish date is obtained by adding this time to the current date.

The result is then compared with the planned operation due date for Job #2. If job #2 is already behind schedule, the interruption time

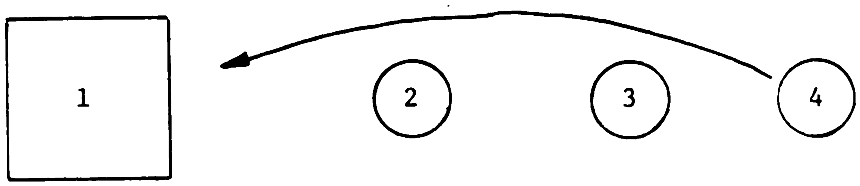


Figure 3.3 Example of Reschedule-in Message

which is set-up and operation time for job #4 is used as the expected time delayed. If the result is on or before the due date, no late penalty cost is assessed. Otherwise, a late penalty cost is assessed by multiplying the cost of this item, penalty percentage, quantity, and the time delayed together. The same procedure is required to assess the possible late penalty cost for Job #3. Hence, the cost of rescheduling for Job #4 is defined as the sum of the late penalty costs of the order affected.

The cost of not rescheduling would be the late penalty cost for Job #4 if it were delayed. The cost of not rescheduling Job #4 is the fixed penalty percentage multiplied by the cost of this component, quantity, and the expected delay. Note that the estimation of both costs is only for reference. These costs may not actually be incurred, because the delay may be made up during the production of higher-level items. In order to make a decision at the present time, the cost estimates are necessary.

It should be noted that the cost estimation of rescheduling for rescheduling messages only assesses the first-order effect of rescheduling of open order, Job #4 in this example. This estimation does not measure the subsequent effect of potential delays of other jobs, or "domino effect", after job #4 is rescheduled. The reason for this treatment is that the first-order effect of rescheduling has an important impact on the production system. Furthermore, the cost estimation of rescheduling would become extremely complicated if the subsequent effects are considered.

2. Rescheduling-out Messages

In Figure 3.4, four jobs are in the queue and one is in process. If there is a rescheduling message to delay the due date of Job #3, Job #3 would now have a lower priority than Job #5. The cost of not rescheduling would be the carrying cost of extra inventory (added labor and overhead) for Job #3 if it were to be processed as scheduled. The period of time over which this additional inventory would be carried is the sum of the operation and set-up times for Job #4 and Job #5. There is no additional cost for rescheduling Job #3 out, assuming that the cost of rearranging the affected jobs is negligible. It is not usual to find that the rearrangement of open orders is only a matter of changing the operational due date on the job ticket in the real-world system. When Job #3 is rescheduled out, Jobs #4 and #5 are expected to complete earlier. As a result, extra inventory cost of Jobs #4 and #5 is incurred. However, the advantage of "freeing" up capacity for the emergency orders should be recognized in reschedule-out situations. Therefore, extra inventory cost of Jobs #4 and #5 is ignored. Because no cost is incurred in this study, rescheduling-out messages are always implemented according to this cost-based dampening procedure--for the cost of not rescheduling is always higher than the cost of rescheduling based on the assumptions made previously.

Evaluation

The criterion for the cost-based dampening procedure is the cost of implementing vs. not implementing rescheduling messages. It incorporates some job-related information, such as operation due date, in order to determine the cost of rescheduling. Therefore, each decision is made without the involvement of subjective perception of system flexibility as required in the two existing global dampening

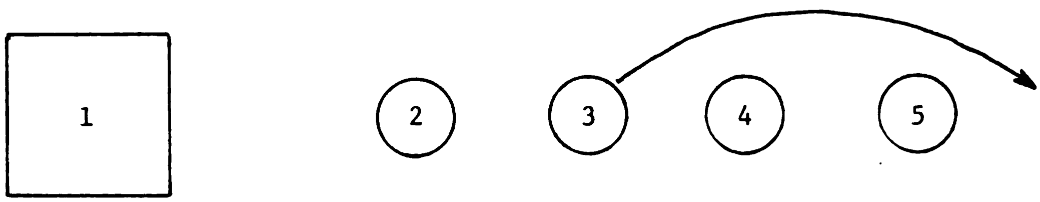


Figure 3.4 Example of Reschedule-out Message

procedures.

However, the cost-based dampening procedure is similar to the automatic rescheduling procedure in terms of the treatment of rescheduling-out messages. Some practitioners, such as Orlicky (1976) and Wight (1982), emphasize the importance of rescheduling-out in order to free up capacity for emergency orders or avoid extra inventory cost.

The major requirement of cost-based dampening procedure is the cost estimation of rescheduling. The establishment of effective retrieval of job-related information may be difficult for some firms. Additional computer software needs to be developed for implementing the cost-based dampening procedure. Therefore, the benefit of implementing the cost-based dampening procedure must be weighed against the cost of developing it.

Less Than Lead Time Order Releases

The dampening procedures described in the previous sections are designed to deal with timing change type of rescheduling messages. The objective of this section is to demonstrate that any type of uncertainty, timing and/or quantity, can be handled by the timing change type of rescheduling messages.

The example in the next three figures illustrates how the timing and/or quantity uncertainty can be resolved by the timing change type of rescheduling messages. Figure 3.5 indicates the original status of an inventory item. Suppose that unplanned events cause gross requirements of 50 in week 3 to increase to 100, and gross requirements in week 1 to change to week 2 (as shown in Figure 3.6). As a result of these changes

Lot-sizing: L4L
Lead time: 4 weeks

		Week 1	2	3	4	5	6	7	8
Gross Requirements		30		50	80	130		70	
Scheduled Receipts		60			160				
On Hand	40	70	70	20	100	-30	-30	-100	-100
Planned Order Releases		30		70					

Figure 3.5 Original Status

in the MRP schedule, there is a net requirement of 30 units in week 3. However, the planned lead time of this item is four weeks. Before releasing a short lead time order for these thirty units, rescheduling logic is applied to check whether there is an open order in the near future. Fortunately, 160 units are scheduled in week 4. Thus, scheduled receipts of 160 in week 4 should be rescheduled to week 3 in order to resolve this problem of coverage.

Note that scheduled receipts in week 1 should be rescheduled to week 2, or extra inventory will be carried one extra period. Therefore, two rescheduling messages are generated in order to cope with the timing and quantity changes. Figure 3.7 shows the result of implementing these rescheduling messages. The order for 40 can be released in the normal lead time.

However, there are exceptional situations where the coverage problem cannot be resolved by rescheduling. Obviously, if the problem of coverage occurs within the normal lead time, and there is no open order to reschedule, an order must be released in less than the normal lead time. The next three figures are used to demonstrate an example of this exceptional situation. Figure 3.8 shows the original status of an inventory item. When uncertainty occurs, gross requirements of 90 in week 4 is reduced to 50, gross requirements of 120 in week 7 is also reduced to 90, gross requirements of 380 in week 9 is rescheduled to week 10, and scheduled receipts of 70 in weeek 2 is reduced to 50 (perhaps due to a scrap problem) (as shown in Figure 3.9). After rescheduling logic is applied, scheduled receipts of 100 in week 3 will be rescheduled to week 2. In Figure 3.10, a new order of 20 must be released in less than the normal lead time to cover the net requirements

Lot-sizing: L4L
Lead time: 4 weeks

		Week 1	2	3	4	5	6	7	8
Gross Requirements			30	100	80	130		70	
Scheduled Receipts		60			160				
On Hand	40	100	70	-30	50	-80	-80	-150	-150
Planned Order Releases		80		70					

Figure 3.6 Problem of Uncertainty

Lot-sizing: 14L
Lead time: 4 weeks

		Week 1	2	3	4	5	6	7	8
Gross Requirements			30	100	80	130		70	
Scheduled Receipts			60	160					
On Hand	40	40	70	130	50	-40	-40	-110	-110
Planned Order Releases		40		70					

Figure 3.7 Solution After Rescheduling Logic Is Applied

Lot-sizing: L4L
Lead time: 2 weeks

		Week							
		1	2	3	4	5	6	7	8
Gross Requirements			80	100	90	100		120	
Scheduled Receipts			70	100					
On Hand	10	10	0	0	-90	-190	-190	-310	-310
Planned Order Releases			90	100		120			

Figure 3.8 Original Status

Lot-sizing: L4L
Lead time: 2 weeks

		Week							
		1	2	3	4	5	6	7	8
Gross Requirements			80	100	50	100		90	
Scheduled Receipts			50	100					
On Hand	10	10	-20	-20	-70	-170	-170	-260	-260
Planned Order Releases		20	50	100		90			

Figure 3.9 Occurrence of Uncertainty Problem

Lot-sizing: L4L
Lead time: 2 weeks

		Week							
		1	2	3	4	5	6	7	8
Gross Requirements			80	100	50	100		90	
Scheduled Receipts			150						
On Hand	10	10	80	-20	-70	-170	-170	-260	-260
Planned Order Releases		20	50	100		90			

Figure 3.10 Solution After Rescheduling Logic
Is Applied

of 20 in week 3. The planners need to make a decision whethere or not these less-than-lead-time planned order releases should be placed at the need date requested.

Research Objectives Defined

The present research project is concerned with achieving three major objectives. The experimental design is developed based on the issues addressed in these three objectives.

Objective 1: Analyze and measure MRP system nervousness conceptually and operationally.

Chapter One provides several definitions of MRP system nervousness. The negative effects of MRP system nervousness are also reviewed. System nervousness reflects the degree of uncertainty which exists within the production system or in its environment, which is not totally undesirable. After a point, however, the negative effects of system nervousness may outweigh its benefit, the ability to maintain priority integrity. Some corrective actions are required to deal with this undesirable result.

In order to adapt to the objectives of the present study, MRP system nervousness is defined as excessive changes in due dates of open orders for manufactured items. When the number of schedule changes is beyond the capability of production system to react, system nervousness is considered "excessive."

This research provides an operational measure of MRP system nervousness, which is useful for MRP users in actually measuring the degree of system nervousness in their own MRP systems. In measuring MRP system nervousness, the difference between rescheduling messages and rescheduling notices should be noted. Referring to the dampening filter presented in Figure 3.1, MRP system nervousness can be measured before or after being filtered through a dampening procedure:

> The number of rescheduling messages provides an indication of the degree of uncertainty within the production system or in its environment. Thus, the pre-dampening measure of system nervousness is a surrogate of production uncertainty. These rescheduling messages become rescheduling notices when they are classified as significant by a dampening procedure. The number of rescheduling notices implies the capability of the production system to react to unplanned events through the use of a dampening procedure.

Two different operational measures will be provided in this research, pre-dampening and post-dampening. Each operational measure of system nervousness has the following components:

1. The type of rescheduling message (A);
2. The type of rescheduling notices (B);
3. The number of rescheduling messages (C);
4. The number of rescheduling notices (D);

Rescheduling-in or rescheduling-out notices or messages should first be considered. It is assumed that rescheduling-in notices contribute to a higher degree of system nervousness than rescheduling-out notices. This is because the shop would have pressing need to implement rescheduling-in notices. If a short-term capacity expansion strategy, such as overtime, is used, the cost of rescheduling would increase.

The number of rescheduling notices is a very important indicator of system nervousness. The implementation of rescheduling notices needs to change the due dates of open orders. The open order priority is then disrupted, which is viewed as MRP system nervousness if a large number of priority disruptions occurs. Therefore, the more rescheduling notices are implemented, the more nervous is the production system.

The study presents a factor rating approach in aggregating these attributes to measure MRP system nervousness operationally:

$$\text{Pre-dampening measure of MRP system nervousness} = \alpha_1 * \text{Number of reschedule-in messages} + \beta_1 * \text{Number of reschedule-out messages}$$

$$\text{Post-dampening measure of MRP system nervousness} = \alpha_2 * \text{Number of reschedule-in messages} + \beta_2 * \text{Number of reschedule-out messages}$$

where α_i and β_i represent weighting factors, and $\alpha_i + \beta_i = 1$ $(i= 1,2)$

It should be noted that these operational measures can be used to compare the degree of system nervousness from period to period in the same manufacturing setting. In other words, the measure of system nervousness is a relative measurement, which can answer the question for which time period of MRP operation is more nervous than the other. The comparison of system nervousness between two different plants can be done only if the same weights are used. Therefore, the operational measure of MRP system nervousness depends upon which attribute the plant emphasizes.

However, the determination of the weighting pattern tends to be subjective. The values of α and β depend upon the perception of the significance of reschedule-in and reschedule-out in the contribution to system nervousness. In order to obtain an appropriate operational measure of MRP system nervousness, it is up to MRP planners to try out several combinations of weighting pattern to match the actual system performance period by period. In this research, these two types of rescheduling notices or rescheduling messages are treated equally. Therefore, the total number of rescheduling messages and rescheduling notices serve as a surrogate measure of pre-dampening and post-dampening system nervousness respectively.

Objective 2: Evaluate selected global dampening procedures.

In the previous sections, two dampening procedures are evaluated in terms of their strengths and weaknesses. The static dampening rule procedure is simple to use, but yet it does not consider such significant factors as the cost of rescheduling. The main features of this procedure are part-independence, static nature, and reliance upon system flexibility.

The automatic rescheduling procedure depends upon the computer's enormous data processing capability to reschedule all the shop orders in order to keep priorities up-to-date. Although priority integrity is a significant goal of shop floor management, it is not the only goal. If priority integrity is treated as the only goal, other important factors may be sacrificed. Obviously, it is not realistic to establish such a single goal for a production system. Total related cost--not the degree of system nervousness--serves as the overall performance measure of a production system. The basic flaw of this procedure is that it tends to ignore the cost tradeoffs of rescheduling.

Objective 3: Develop and evaluate the cost-based dampening procedure and compare it with the current procedures.

One common weakness of the existing dampening procedures is that they ignore the cost tradeoffs of rescheduling. Implementation of rescheduling open orders usually requires some extra effort; which is not cost-free. Partly because of the difficulty of estimating costs at this detailed level, the cost of rescheduling is oftentimes neglected.

In this study, the costs of rescheduling and not rescheduling are discussed in detail. Although cost estimation is not an easy task, it is an important part of justifying implementation of a rescheduling message. The cost estimation, no matter whether or not the costs actually occur, is used as a reference for making rescheduling decisions. It provides decision makers with vital information to screen out insignificant rescheduling messages. In turn, the degree of system nervousness is reduced, while maintaining a reasonable priority integrity.

An experimental design is developed in the study to achieve Objective 3. The design includes alternative dampening procedures, different lot-sizing rules, uncertainty levels, and capacity utilization levels. The primary performance measure is total related cost. This experimental design will be further discussed in the next chapter.

Summary of Chapter Three

This chapter has described the decision-making mechanism of dampening procedures to be tested, followed by the evaluation of these dampening procedures. The problem of less than lead time order releases is recognized. The research objectives which will be specifically examined are also described. The next step is to describe the test environment in which these objectives are examined.

CHAPTER FOUR

SIMULATED FACTORY

This chapter describes the major characteristics and operating procedures of the "simulated factory", that is used as the experimental vehicle for this study. The chapter begins with a discussion of the selection of compute simulation as the research method. It is followed by a brief presentation of the original simulated factory developed by Melnyk (1980). Finally, the revisions of some operating characteristics in this factory are presented in order to adapt to the research objectives defined.

Computer Simulation

The research technique used in this study is computer simulation, which can be simply defined as experimentation with a model of a real system (Shannon, 1965, p. 10). Computer simulation is commonly used in production research. Biggs (1975), Collier (1977), Melnyk (1980), and Penlesky (1982) have used a hypothetical multi-product, multi-state simulated factory in their studies of MRP-related production problem.

Laboratory test and field test are the other possible approaches to experimenting with alternative dampening procedures to cope with MRP system nervousness in this project. Laboratory test requires hand calculation, with the model's output then compared with a predetermined optimal solution (Wiest, 1967, B367). Field test applies the model to a real world problem to study its behavior (Wiest, 1967, B366-B367). These two research methods are either infeasible or inapplicable to accomplish the research objectives set forth for this study. It is impractical to use a real world system to replicate experiments under different sets of operating conditions. Furthermore, the research problem as defined is not amendable to mathematical analysis by existing analytical techniques, such as linear programming, due to its size and complexity. Therefore, a computer simulation of a hypothetical factory is appropriate as the research method for this project.

Computer simulation does provide several advantages over other research methods for carrying out this study. Computer simulation enables the researcher to investigate the behavior of a simulated factory over time as it responds to changes in several operating conditions. Also, this method allows for experimentation of alternative dampening procedures and evaluation of their impacts on the operation of simulated factory. The time compression feature of simulation is advantageous in experimentation with a system over a relatively long time frame (Shannon, 1975, p. 11). However, the simulation time frame selected in this research is actually a compromise between the cost of simulation time and reliability of results to achieve a desired statistical accuracy.

Simulated Factory

The hypothetical simulated factory used in this research was developed by Melnyk (1980), who in turn derived it from Winters' FACTRY simulation (p. 127). The details regarding parts manufacturing in this factory were taken from the NATCO jop shop case (Berry & Williams, 1972).

Figure 4.1 provides a schematic diagram of this simulated factory, which consists of three departments: an assembly line, a subassembly line, and a job shop. There are 15 end items, 7 subassemblies, 15 parts, and 8 raw materials. The major characteristics of the original simulated factory are described as follows.

<u>Master production schedule</u>

MPS is simply a production statement of requirements for end items, by date and quantity (Orlicky, 1975a, p. 232). A planning horizon of 50 weeks is selected for this factory, which is commonly used in some firms (Dippold, 1975, p. 359). The MPS provides the simulated factory with a form of discipline and a certain amount of production load leveling. This objective is accomplished by deriving the MPS from the repetition of an "MPS cell". This cell is a seven week schedule covering the production of all 15 end items. Initially, the production quantity for each end item is set at a level which is sufficient to cover seven weeks' worth of demand.

<u>Production and inventory control</u>

A weekly regenerative MRP system is used as the production scheduling and inventory control technique in this factory. In this MRP system, the MPS is exploded very week. During each explosion, all gross requiements and net requiremnts for each inventory item are recalculated and the planned order releases are re-created after lead time offsetting. This explosion process is repeated until all the levels in

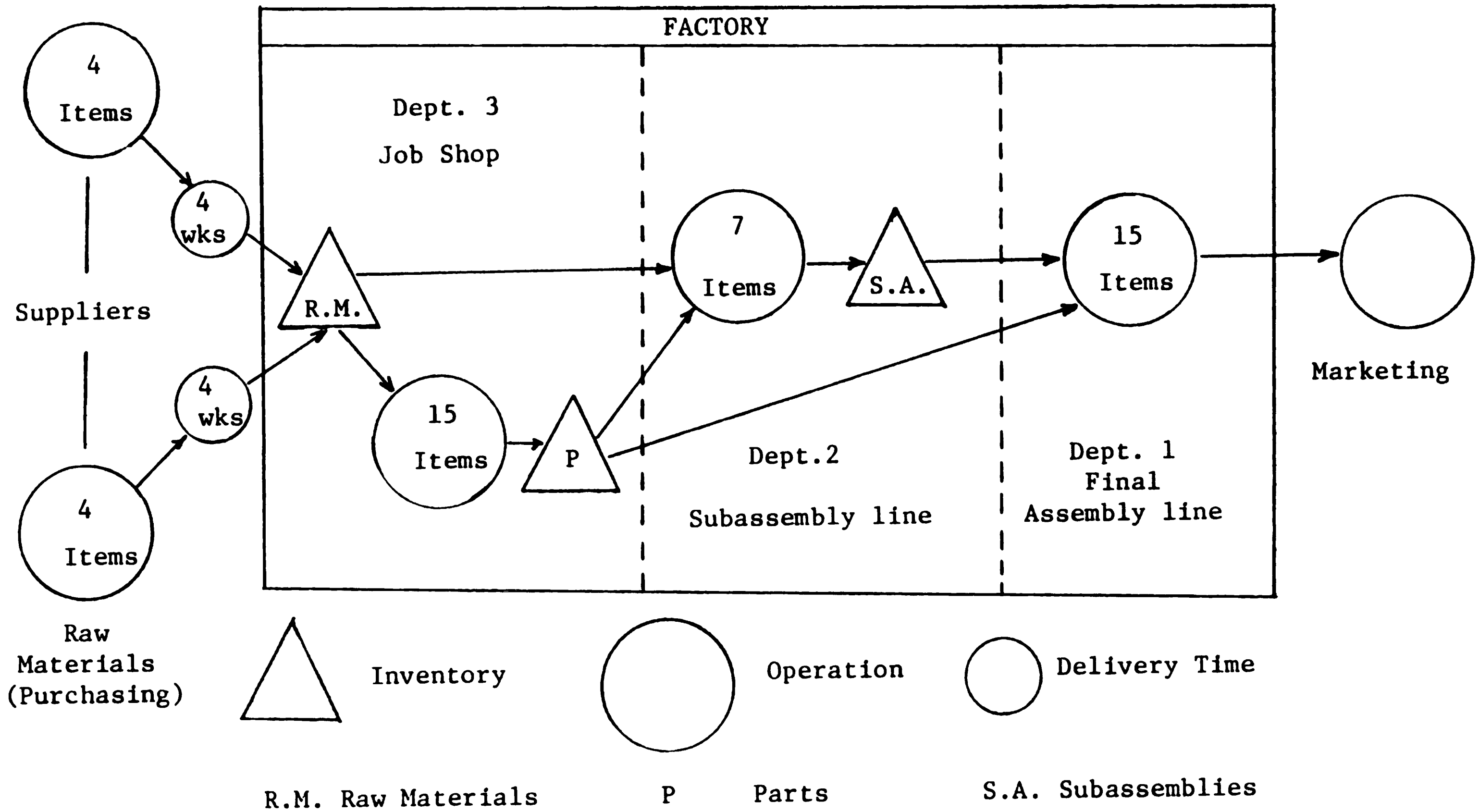


Figure 4.1 Diagram of Factory Organization

the bill of materials have been processed.

Shop floor management

Routing can be defined as the sequencing of operations to complete a shop order at a certain work center. In this factory, each of the 37 manufactured items follows its own different set of production routing.

In terms of inventory withdrawal procedure, kitting is not allowed. That is, components or subassemblies would not be allocated prior to production. This is a very important procedure emphasized by the MRP system in order to reduce work-in-process inventory.

As for the order releasing procedure, an open order enters a queue to wait for the machine to be precessed. When sufficient components have been withdrawn, the production starts. Otherwise, the order is removed from the machine, and is placed in the shorted queue. The order moves from work center to work center based on its routing requirements to complete the production. Finally, stockout of end items is permitted in this simulation.

Another policy in shop floor management is that of order splitting. A large production lot can be split up into sublots, so that the completion time can be reduced. Other shop floor policies are summarized as follows.

1. Worker overtime is not considered.

2. Once a batch is started on a machine, it cannot be preempted or interrupted.

3. Workers can be transferred within the department, but not between departments.

Manufacturing lead time

Plossl and Wight (1967) maintained that the manufacturing lead time should include processing time, set-up time, queue time, move time, and wait time (the time a job spend waiting to be moved). Processing times are predetermined and remain constant over the entire simulation. So is the set-up time per operation. In Melnyk's model, there are several lead time forecasting techniques used as an experimental factor in his study. However, in order to obtain an appropriate estimate of manufacturing lead time for the uncertain environment studied in this project, a trial run is used to provide the lead time estimates for the component parts and subassemblies.

Costs

Since the total related cost is used to measure the effectiveness of the production system under study, information on several costs needs to be collected. Standard costing has been used in this simulated factory to determine inventory carrying costs and transfer costs. A standard cost is calculated for each inventory item. This cost equals to the sum of the standard cost of needed lower level components, the cost of the estimated processing time and an allocation to cover overhead. Furthermore, raw materials and labor costs are expensed at the time that the relevant end items have been completed and transferred. Inventory carrying costs and set-up costs, on the other hand, are treated as period expenses.

Inventory carrying cost is 2 percent per month. Stockout cost consists of 'stockout' cost and continued backorder cost. 'Stockout' cost is assessed when the due date is first missed. Backorder cost is computed as the percentage late penalty multiplied by the additional week(s) delayed.

Capacity utilization

The production capacity is set at the start of the simulation by specifying the maximum number of man-machine hours available in each department. The capacity is then adjusted to approximate a certain capacity utilization. In Melnyk's simulation, the available capacity was set to yield an average capacity utilization of 95% for the assembly lines and 75% for the job shop.

Consideration of human factor

Penlesky (1982) discussed the behavioral effects of MRP system nervousness. Planners may either stop trying to perform an impossible task; or choose rescheduling messages to implement randomly; or lose faith in the priority integrity planning system, such as the shop foremen's instinct. The worst result is the loss of credibility of MRP system's formal priority planning capability. However, this research does not involve the complicated decision-making process of human.

Revisions of Operating Features

Several operating characteristics discussed previously need to be modified in order to adapt the simulation to the research objectives for this study. These revisions are discussed below.

MRP System with Rescheduling Capability

An MRP system with rescheduling capability is included in this simulated factory. Orlicky (1976) suggested that the MRP system be programmed not to generate a new planned order to cover net requirements but to request the rescheduling of the closest open order. Thus, this rescheduling capability is based on netting logic which makes the assumption that an existing scheduled receipt will be rescheduled to an earlier date in order to satisfy the requirement before a new order is created or released (Wight, 1978, p. C1).

Orlicky (1976, p. 168) proposed two tests for programming rescheduling logic in the MRP system:

1. Are there any open orders scheduled for periods following the period in which a net requirement appears?

2. Is there an open order scheduled for a period in which the gross requirement equals or is less than the on-hand quantity at the end of the preceding period?

He also noted that an open order should be cancelled when on-hand quantity in the period preceding the scheduled receipt of the order is sufficient to cover all remaining gross requirements. In this dissertation, the rescheduling logic is based on these two tests. The first test is designed to determine whether a reschedule-in message should be generated. That is, an open order should be rescheduled in order to cover net requirements in the earlier time period. The second test is used to determine a reschedule-out message for an open order that is not needed in a time period.

Figure 4.2 is used to illustrate how the MRP system works in this study. In the beginning of each week, information on the uncertainty under study, scrap and MPS change, must be collected. Scheduled receipts are then changed to reflect these changes. During the regeneration of the MRP system for this week, rescheduling logic is

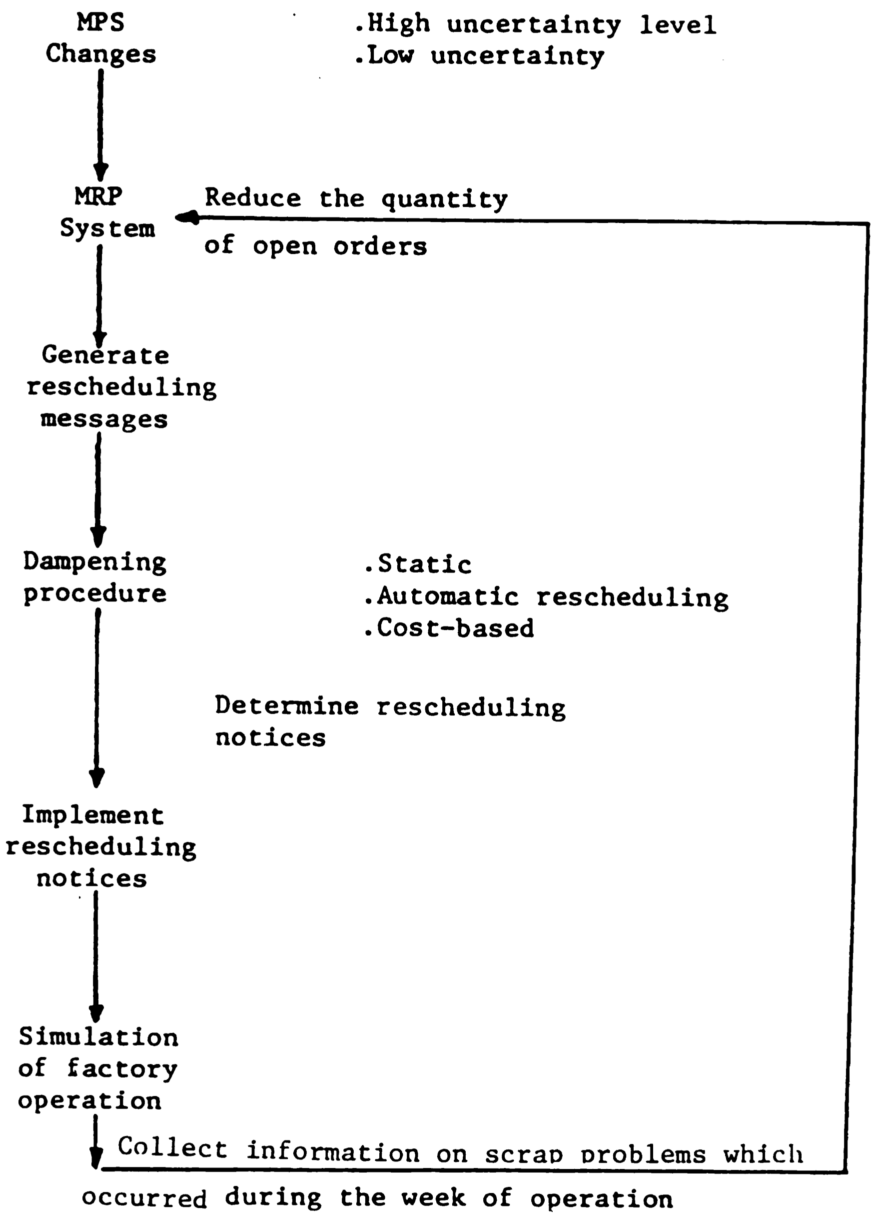


Figure 4.2 Production Control in Simulated Factory

applied. Then, rescheduling messages are generated after the MRP system is replanned. Global dampening procedures are used to determine whether these recheduling messages should be implemented or not, i.e. determine which are rescheduling notices. All these need to be done in the beginning of each week. Finally, the simulation of factory operation is conducted with the results of the global dampening procedures. The major elements in Figure 4.2 are further discussed in the follwoing sections.

Production Uncertainty

As described in the research framework, there are two types of uncertainty, environmental and system uncertainty, to be considered in this study. The environmental uncertainty is represented by demand uncertainty, such as cancellation of customer orders. Consequently, the MPS is subject to change from period to period. Both timing and quantity changes in the MPS are considered to reflect the dynamics in the real world.

1. Environment Uncertainty

Figure 4.3 provides a flow chart which describes how the MPS changes are generated. The uncertainty level of MPS is determined by α, which is 0.15 for the low uncertainty level and 0.3 for the high uncertainty level. In this flow chart, once a production requirement needs to change, a equal chance (1/3) is assumed for the occurrence of timing, quantiity, or simultaneous change. A uniform distribution is used to generate timing changes in the MPS. However, the range of the uniform distribution should vary with the time period in the planning horizon. The rationale is that the farther into the future, the larger the

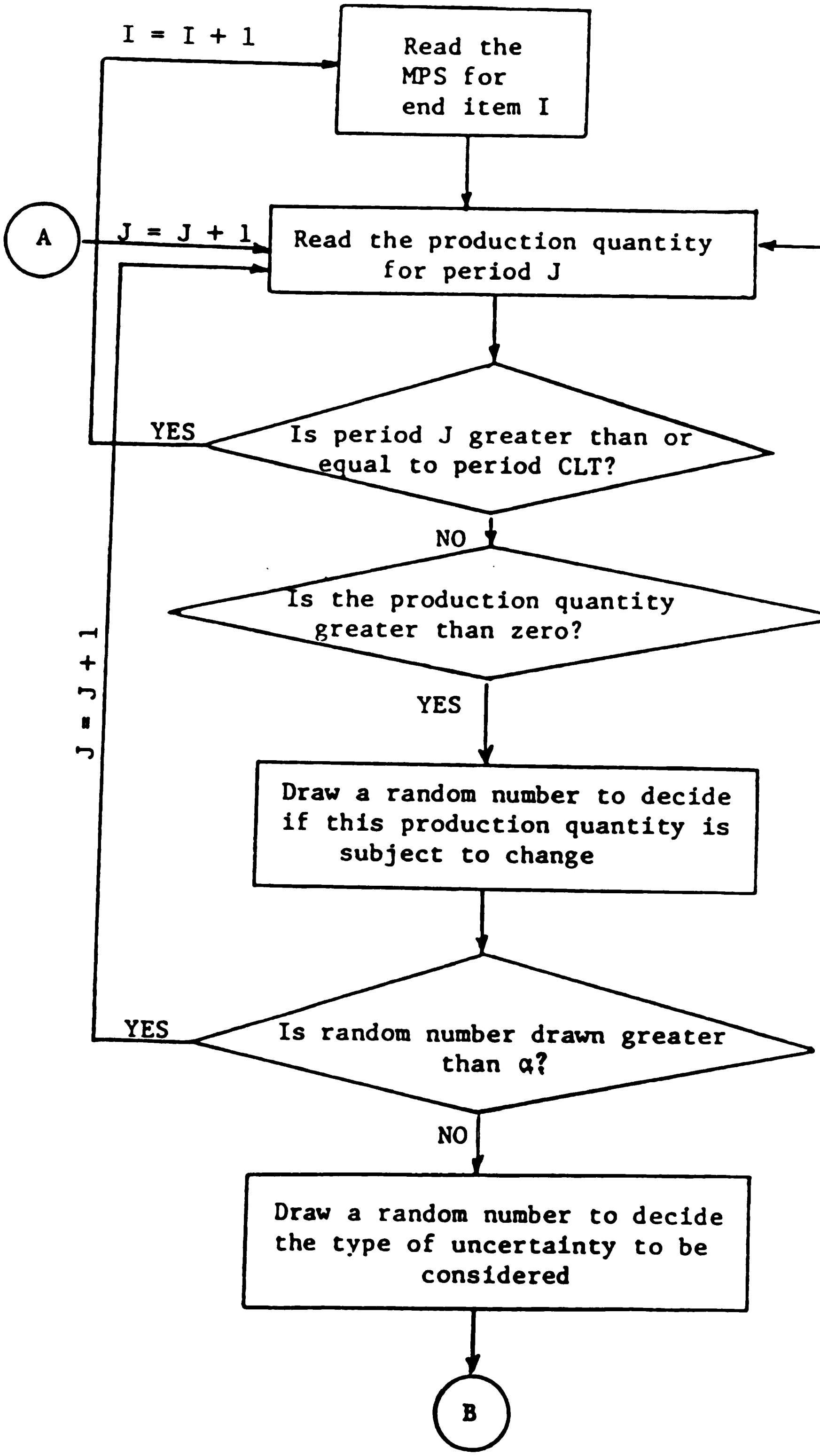


Figure 4.3 Flow Chart of Inducing MPS Uncertainty

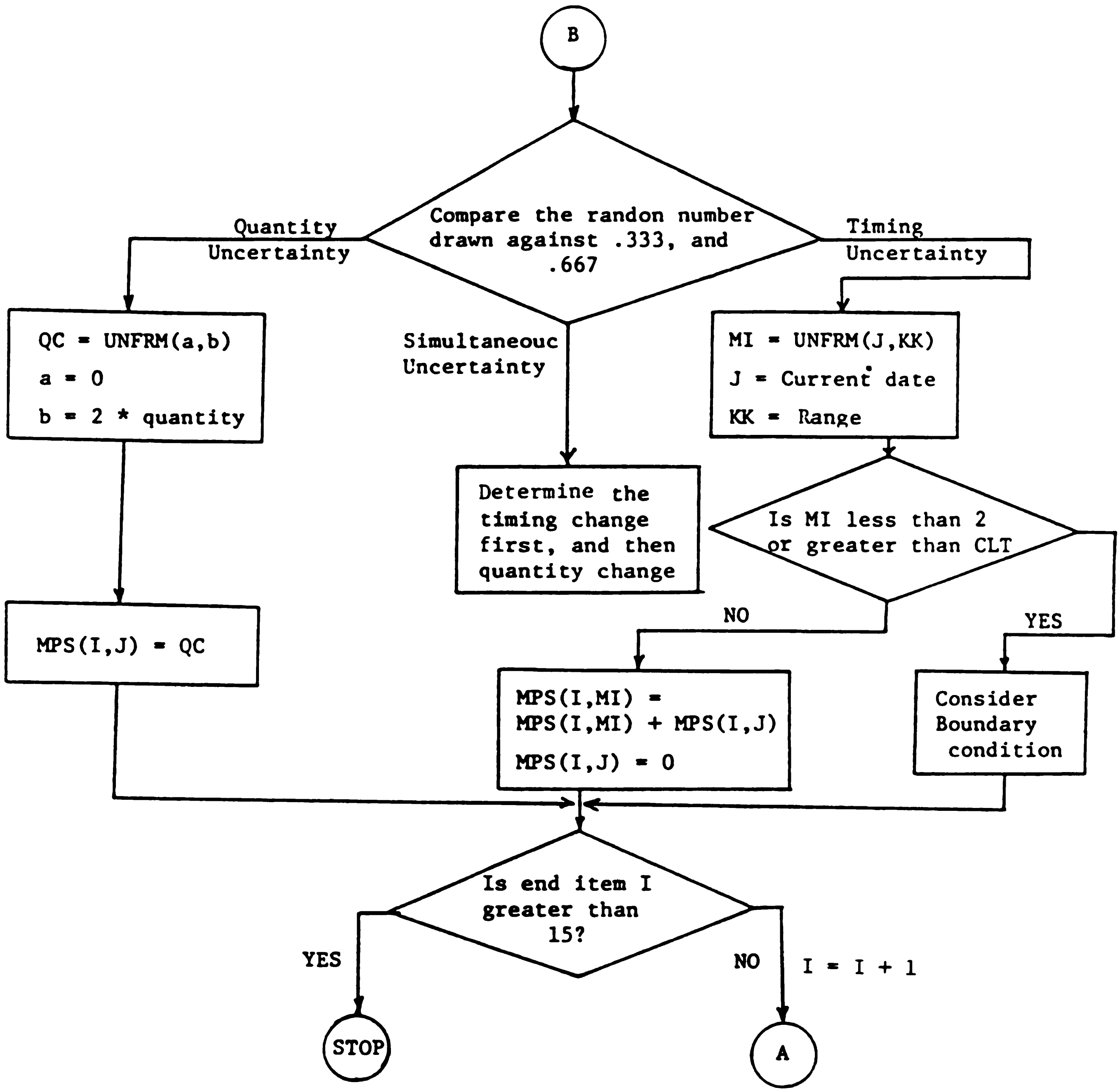


Figure 4.3 (cont'd)

magnitude of possible change. Therefore, equation (4.1) is used to set up the range for the uniform distribution at period J. It should be noted that some orders cannot be moved into the period beyond the current period because the left bound of planning horizon is the current period. The boundary condition may also occur at the cumulative lead time beyond which the MPS changes have no impact on the requirements of the lower level items. In this case, orders are not moved beyond the cumulative lead time and will be placed at the date of cumulative lead time.

$$Range_J = kk * (t_J - t_0) \qquad (4.1)$$

where: t_J = time period J

t_0 = the current period

kk = the slope of the uncertainty lines (See Figure 4.4)

Figure 4.4 is used to illustrate how different degrees of uncertainty are introduced in this study. Note that no time fence is established in the simulation since none of the local dampening procedures is considered. Consequently, a certain degree of uncertainty exists from the beginning of planning horizon. A varying degree of uncertainty along the planning horizon is considered in this research. The probabilities of .15 and .30 at the cumulative lead time of an end item represent the low and high levels of uncertainty, respectively. Therefore, the slopes of these two lines determine the different degrees of uncertainty, which can be obtained from the following equation (4.2).

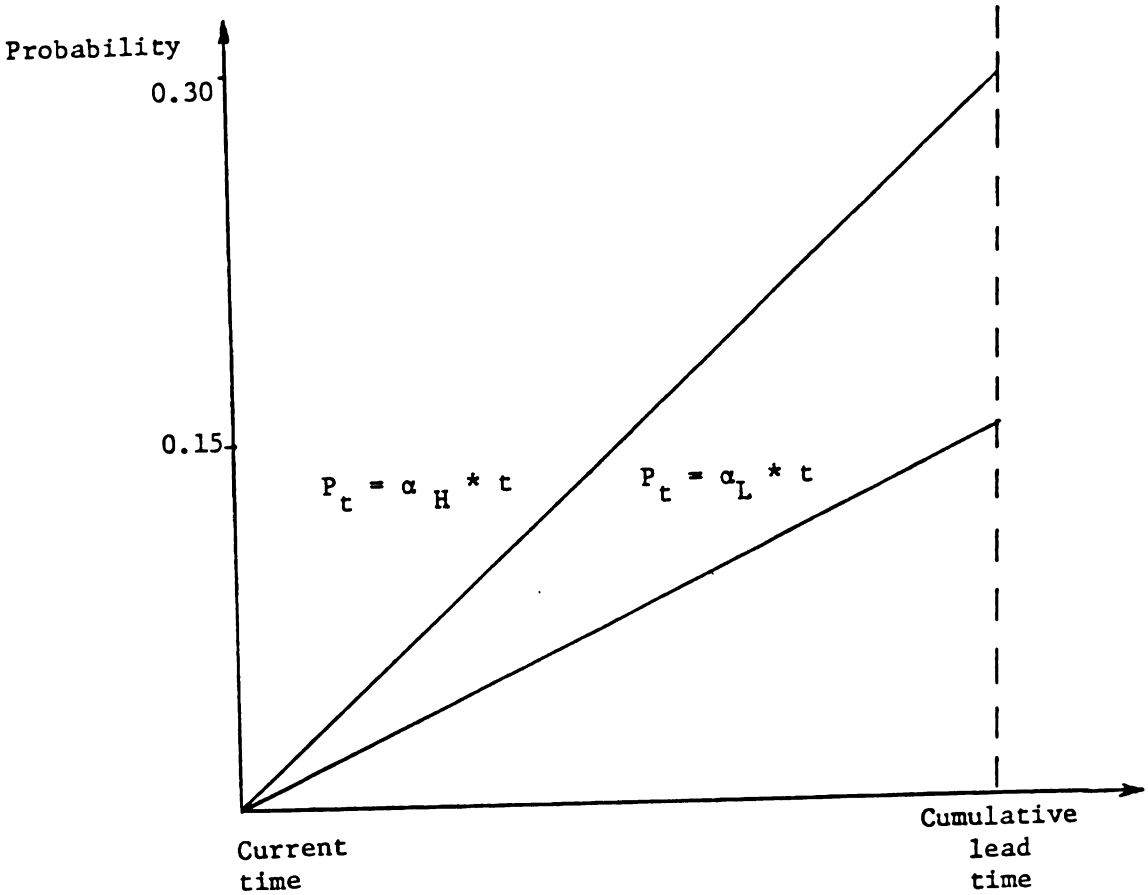


Figure 4.4 MPS Uncertainty

$$\alpha_L = 0.15/CLT$$
$$\alpha_H = 0.30/CLT \qquad (4.2)$$

Where α_L and α_H represent the slopes of the uncertainty lines

As for the quantity change in the MPS, a uniform distribution is also used to simulate the change which ranges from 0 to two times of the original quantity. The reason of using these two values is mainly to balance out the uneven loading resulted from the MPS changes in the long run. In the case of simultaneous change, the timing change is considered first.

2. System Uncertainty

Scrap is used to represent system uncertainty, which is simulated by the reduction of an open order when the scrap transaction occurs. Whenever an operation of an inventory item is completed in a machine center, it is subject to the potential occurrence of scrap transaction. In other words, an inspection is made to determine whether there are any defective items and the number of defective items.

The probability of the occurrence of scrap is governed by the experimental factor of uncertainty level. Three and six percent are selected to represent the low and high uncertainty levels respectively. In the job shop, each part needs to go through seven to ten operations in order to complete the part. Assuming that independence exists between operations, there is from 73 to 80 percent chance that a part would go through the job shop without having a scrap problem for the low uncertainty level. There is from 54 to 65 percent chance that an open order would go through the job shop without having a scrap problem for the high uncertainty level. After the scrap transaction occurs in one operation, a uniform distribution between 0 and 60 is used to determine the percentage of scrap. The expected results of these uncertain events during the week are then reported at the weekend. The open order file is adjusted to reflect expected results prior to weekly MRP replanning.

Capacity utilization

There are several methods that can be used to manipulate the capacity utilization rate. Job operation time can be scaled to obtain a different capacity utilization level. The factory configuration, expressed in terms of production time available in these three production departments, can be changed for a given demand loading to obtain a different capacity utilization level. In this study, the MPS used to generate 60 percent of capacity utilization is multiplied by a factor, 1.4, to obtain the high capacity utilization level. This method is used because it can be easily done and does not change the configuration of the factory.

Dampening procedures

The subprograms for global dampening procedures tested in this research are added to this simulated factory and all incorporated into the MRP system. The parameters and information required in each dampening procedure are discussed as follow:

1. Static dampening procedure

The mechanism used in the static dampening procedure establishes a rescheduling fence defined by "a" and "b". The determination of parameters "a" and "b" is based on the result of several trial runs undertaken in order to select an appropriate "no rescheduling fence" for this research. Although this search technique is not meant to find an optimal "no rescheduling fence", it is better than just following the rule-of-thumb suggested by Mather (1977). The rationale is that a "no rescheduling fence" is established to reflect system flexibility of an individual production system.

Based on the results of several trial runs, a "no rescheduling fence" is established so that rescheduling in less than one week or rescheduling out less than two weeks would not be implemented. These parameters selected also enable the static dampening procedure to perform similarly to the "no rescheduling procedure". The conclusion drawn about the static dampening procedure may provide some insights about the "no rescheduling procedure" because of this similarity.

2. Automatic rescheduling procedure

In the automatic rescheduling procedure, the minimum lead time for each open order must be calculated operationally. In this research, the minimum lead time is computed as the sum of operation time plus set-up time for remaining operations, plus any remaining opreating time for processing the current order on the machine. Once an open order is moved into this minimum lead time interval, it will be placed at the minimum lead time's period. Otherwise, the open order is rescheduled as the rescheduling notice requests.

3. Cost-based dampening procedure

The cost-based dampening procedure is based on a comparison between the cost of implementing a rescheduling message and the cost of not implementing it. The cost estimations of rescheduling and not rescheduling are, thus, very important in the cost-based dampening procedure. Therefore, some variables, such as the operation due date and penalty charge, are added to keep track of these cost estimates in order to make rescheduling decisions at any period.

Perfomance Measures

Two types of performance measures are used in the present research: primary and secondary measures. The performance measures are accumulated from the beginning of the steady-state condition until the end of the simulation run.

Primary Measure

The primary measure, total related cost, is used in evaluating the impact of alternative dampening procedures on the overall performance of the production system. Total related cost are defined as the sum of shortage costs, backorder costs, inventory carrying costs, and set-up costs. This measure is a comprehensive one for assessing a production system's ability to manage inventory level and plant operation. However, the use of total related cost as a performance measure has a potential problem. The total related cost tends to aggregate the cost components which may confound the individual effects of cost components. Therefore, it may be interesting to investigate the individual cost components under some operating conditions. Furthermore, the stockout and backorder costs were combined as the shortage cost in the analysis of cost components.

The total related cost is used as the performance measure in hypothesis testing regarding the interaction effects and main effects of experimental factors tested. The use of single performance measure is advantageous in a simulation study: the multiple response problem can be avoided. There is no satisfactory method for dealing with the multiple-response problem (Naylor, 1971, p. 28).

Secondary Measures

Secondary measures may be used to explain any unusual simulation results. The following secondary measures are taken during the data collection.

1. Inventory carrying cost for all items stored
2. Finished goods tardiness
3. Stockout cost
4. Shortage cost
5. Number of rescheduling-in messages
6. Number of rescheduling-in notices
7. Number of rescheduling-out messages
8. Number of rescheduling-out notices

Summary to Chapter Four

This chapter first described the operating characteristics of the simulated factory used as an experimental vehicle in this study. The revisions of some operating features were also presented in order to adapt to the simulation model to the research objectives defined. The experimental design used to investigate the performance of dampening procedures is presented in the next chapter. The statistical methods used to analyze the experimental results are also described next.

CHAPTER FIVE

EXPERIMENTAL DESIGN AND STATISTICAL METHODS

This chapter begins with a presentation of the experimental design used in the research. Justifications for selecting the experimental factors and performance measures are discussed in detail. Next, tactical considerations in the simulation study are discussed. Then, the hypotheses are stated and their relationship to the objectives of the study is discussed. The chapter concludes with a brief description of the statistical methods used to analyze the simulation results.

Experimental Design

The major objective of this thesis is to evaluate the effectiveness of using alternative dampening procedures to cope with MRP system nervousness under various operating conditions. The experimental design used is very important in any simulation study, for it determines the form of statistical analysis applied to simulation results (Shannon, 1975, pp. 144-165). Due to the exploratory nature of the study, a full factorial design was used. The factors and their levels are shown in Figure 5.1. In a full factorial design, all the levels of a given factor are combined with each level of the other factors. Main effects and key interaction effects can be determined via this type of factorial design (Kleijnen, 1975, pp. 289-290). Furthermore, the factorial design

$PM = F(DP_i, LS_i, UL_i, CL_i)$

PM = Performance Measure

DP_i = Global Dampening Procedure

i = 1 Static Dampening Procedure

i = 2 Automatic Rescheduling Procedure

i = 3 Cost-based Dampening Procedure

LS_i = Lot-sizing Rule

i = 1 Lot-for-lot (L4L)

i = 2 Economic Order Quantity (EOQ)

UL_i = Uncertainty Level

i = 1 Low Uncertainty Level

i = 2 High Uncertainty Level

CL_i = Capacity Level

i = 1 Low Capacity Level

i = 2 High Capacity Level

Figure 5.1 Factorial Design

is fixed in the sense that the conclusions of the study pertain to the particular levels included in the factorial design.

The total number of simulation runs is the number of combinations which can be obtained via the use of three dampening procedures, two uncertainty levels, two lot-sizing rules, and two capacity utilization levels. Thus, 24 runs are required when a full factorial design is used for each replication. The rationale for selecting these factors is described below.

Global Dampening Procedures Tested

The selection of the three global dampening procedures utilized was discussed previously. Here, the reasons for excluding two extreme cases--the "no dampening procedure" and the "no rescheduling procedure"--are examined further. The automatic rescheduling procedure is very similar to a "no dampening procedure", except for the treatment of rescheduled orders within a minimum lead time. If automatic rescheduling procedure does not perform well compared with other dampening procedures, the implication will be that a "no dampening procedure" can only be worse. The rationale behind this implication is that the automatic rescheduling procedure does take into account infeasibility of rescheduled orders, and hence does prevent accumulation of past-due orders. The "no dampening procedure" tends to accumulate past-due orders, leading to considerable late penalties.

One may question whether this generalization may not hold true in all the situations. Based on the major conclusion noted in Penlesky's (1982) study, it indicated that the automatic rescheduling procedure performed indifferently from "no dampening procedure" in one particular set of operating condition. Therefore, the exclusion of the "no dampening procedure" is considered appropriate.

As for the "no rescheduling procedure", some companies have used this approach to resolving rescheduling problems. Basically, the production schedule is frozen over a period of time, so that no rescheduling message are generated. This approach ignores the MRP system's rescheduling capability, which is frequently mentioned as one of the most important functions of an MRP system. The major findings of Penlesky (1982) indicated that a "no rescheduling procedure" is worse than a "no dampening procedure" under a broad range of operating conditions tested in his research. The "no rescheduling procedure" is also worse than any of the four rescheduling procedures tested by Penlesky (1982). From this previous research, the result leads to the exclusion of "no rescheduling procedure" in the current study.

<u>Degree of Uncertainty</u>

Two different types of uncertainty are simulated in this study. Scrap represents the system uncertainty which occurs within the production system while the MPS changes represent the environmental uncertainty which occurs outside the production system. For the scrap, the degree of uncertainty is the probability that a machine center will be found to have a scrap. Two different probabilities, 3 percent and 6 percent, were selected to represent low and high degrees of uncertainty, respectively. A uniform distribution between 0 and 60 is used to determine the percentage of scrap. For MPS changes, 0.15 and 0.30 will be used to represent the low and high degree of uncertainty respectively. Under the low uncertainty level in the study, there is 15 percent chance that a job, which just completed an operation, is found to have a scrap. The necessary contrast between the low and high uncertainty levels was assured in some trial runs to select these parameters.

Lot-Sizing Rule

The Lot-sizing rule is the algorithm determining the quantity of an item to be produced when a shop order for this item is released to the shop. Lot-sizing rule is considered a major cause of system nervousness (Steele, 1975, p. 85). A dynamic lot sizing rule may require new lot sizes each time replanning is generated. The new lot sizes must then be exploded through the product structure, which in turn generates rescheduling messages for the lower-level items. Therefore, a fixed order quantity lot sizing rule has been proposed to dampen system nervouness (Carlson, 1980; Steele, 1975). Theisen (1974) suggested that MRP users adopt a fixed quantity lot sizing rule at the high level item and dynamic lot sizing rule at the lower levels.

The inclusion of this factor allows investigation of the impact of dynamic lot-sizing rule on overall production system performance via its impact on MRP system nervousness. Therefore, only the nature of the lot-sizing rule is dealt with--namely, static lot-sizing or dynamic lot-sizing rule. The selection of a specific lot-sizing rule to handle rescheduling problems is not the focus of the present study. Also, the selection of a lot-sizing rule is subject to many environmental factors, such as cost parameters, demand variability, and so forth (Berry, 1972; Silver & Meal, 1968, 1973). As a result, Lot-for-Lot (L4L) and economic order quantity (EOQ) are used to represent dynamic and static lot-sizing rules respectively in the present study, because L4L and EOQ are the commonly used lot sizing rules (Mather, 1985).

Planned Capacity Utilization Level

It can be observed that a production system with more uncommitted capacity can resolve rescheduling problems more easily than one with higher utilized capacity (Jones, 1973). Penlesky (1982) tested a hypothesis and concluded that a manufacturing facility must have sufficient capacity to respond to changing open order priority in order for a "no dampening procedure" to have a favorable effect on system performance. The capacity utilization of approximately 60 and 80 percent are used in this research. These levels have been utilized in other job-shop study (Jones, 1973). Because variable routing is used in the job shop, a utilization rate of 80 percent contributed to considerable congestion in the simulation. Therefore, 80 percent is used to represent the high capacity utilization level in this study. From the preliminary investigation of simulation results, 60 percent is appropriate to represent the low capacity utilization level.

Tactical Aspects of Simulation

There are several important tactical considerations of simulation experiment that should be addressed.

Determination of Data Collection Strategy

There are two major approaches to collecting sample data, replication and batch sampling. In this research, batch sampling is selected mainly because it eliminates the need to reinitialize by running the model to steady state for each replication. Therefore, the simulation length is determined by selecting a batch size and the number of batches. The batch size represents the number of observations upon which each sample mean is based. The number of batches represents the number of sample means used to conduct statistical analysis in order to achieve a desired level of significance.

A 25-year run is used to collect the data to determine the batch size required in this study. The EOQ/ROP operation in the first year was not included in the data analysis. Thus, the monthly data of the total related cost and finished goods tardiness were collected for 24 years. Four different batch sizes (3, 6, 12, and 24 months) were considered. Then, the Durbin-Watson test was used to test if the data grouped in these four batch sizes are autocorrelated. Durbin-Watson's d statistic for these four batch sizes are tabulated in Table 5.1. Although the finished goods tardiness is not the primary perfomance measure used in this study, it is used, in addition to the total related cost, to confirm the appropriateness for selecting the correct batch size.

In the SAS User's Guide (1982), it is suggested that the value of d is close to 2 if the data are not autocorrelated. Also, according to the sampling distribution of d, the upper and lower limits of d at the .01 level of significance are also provided in Table 5.1 (Johnston, 1972). The following rules are used to test the autocorrelation:

If $d < d_L$: reject the null hypothesis of zero autocorrelation

If $d > d_U$: do not reject the null hypothesis

If $d_L < d < d_U$: the test is inconclusive (Johnston, 1972, p. 252)

where d_L and d_U represent the lower and upper bound of d respectively

The batch size of 3 months and 24 months are ruled out of consideration because the value of d for the total related cost in 24

Table 5.1 Statistics for Determining Batch Size

	Batch Size 3 months (n = 96)	6 months (n = 48)	12 months (n = 24)	24 months (n = 12)
Total Related Cost	1.899	1.909	1.781	3.302
Finished Goods Tardiness	1.572	1.777	2.171	2.088
d_L	1.51	1.49	1.04	N/A
d_U	1.55	1.58	1.20	N/A

months' series is well above 2, and the value of d for the finished goods tardiness in 3 months' series is very close to the upper bound of d. Based on the statistical analysis and limited computer resources, the batch size of 6 months was selected in this study.

Determination of Sample Size

The length of the simulation run is determined by the sample size required to achieve the desired statistical significance. Neter and Wesserman (1974) suggested that planning of sample size be approached by controlling the risks of making Type I and Type II errors (power approach), by controlling the widths of desired confidence intervals (estimation approach), or by a combination of these two methods. They indicated that the difficulty of using the power approach is the determination of how much factor means must differ which became important to recognize the statistical significance of different dampening procedures tested. Also, it is usually not easy to arrive at a meaningful specification of noncentrality parameter (Neter & Wesserman, 1974, p. 494). Therefore, the estimation approach is used to determine the sample size in this study.

The essence of the estimation approach is to determine the expected widths of the confidence intervals for various sample sizes given an advanced judgment of the standard deviation. The following equation is then used to determine the necessary sample size.

$$n = \frac{t^2 s^2}{d^2}$$

where n = sample size

t = tabulated t value for the desired confidence level and the degree of freedom of the initial sample

d = the half-width of the desired confidence interval

s = the estimate of the variance obtained in the sample or pilot run (Shannon, 1975, p. 189)

Based on the data of the long simulation run described earlier, s is equal to 6,559,460,933 and t is equal to 1.685 for the total related cost at .01 level of significance. The half-width of the desired confidence interval, d, determines the sample size. Table 5.2 provides the sample size for different values of d. The percentage of d relative to the average monthly cost during this 24-year run is also presented. With the consideration of computer cost, a sample size of 10 is selected because the width of $43,155 seems to be a reasonable estimate as the half-width of the desired confidence interval.

Model Initialization and Steady State Condition

The problem of model initialization is basically a disadvantage associated with any simulation study because modelers must consider carefully how to start up the simulation model and when to start taking data (Shannon, 1975, p. 182).

There is a rather unique feature in this simulation study in terms of model initialization, as shown in Figure 5.2. The first phase of simulation is the factory operation with EOQ/ROP inventory control technique. By the time MRP system starts, the production system is expected to reach a fairly stable condition in terms of inventory level or order lateness. Although there still is a transient period after the

Table 5.2 Statistics for Determining Sample Size

d	$100,000	$50,000	$43,155	$30,000
Percent	16.32	8.16	7.04	4.9
Sample Size	1.86	7.45	10	20.69

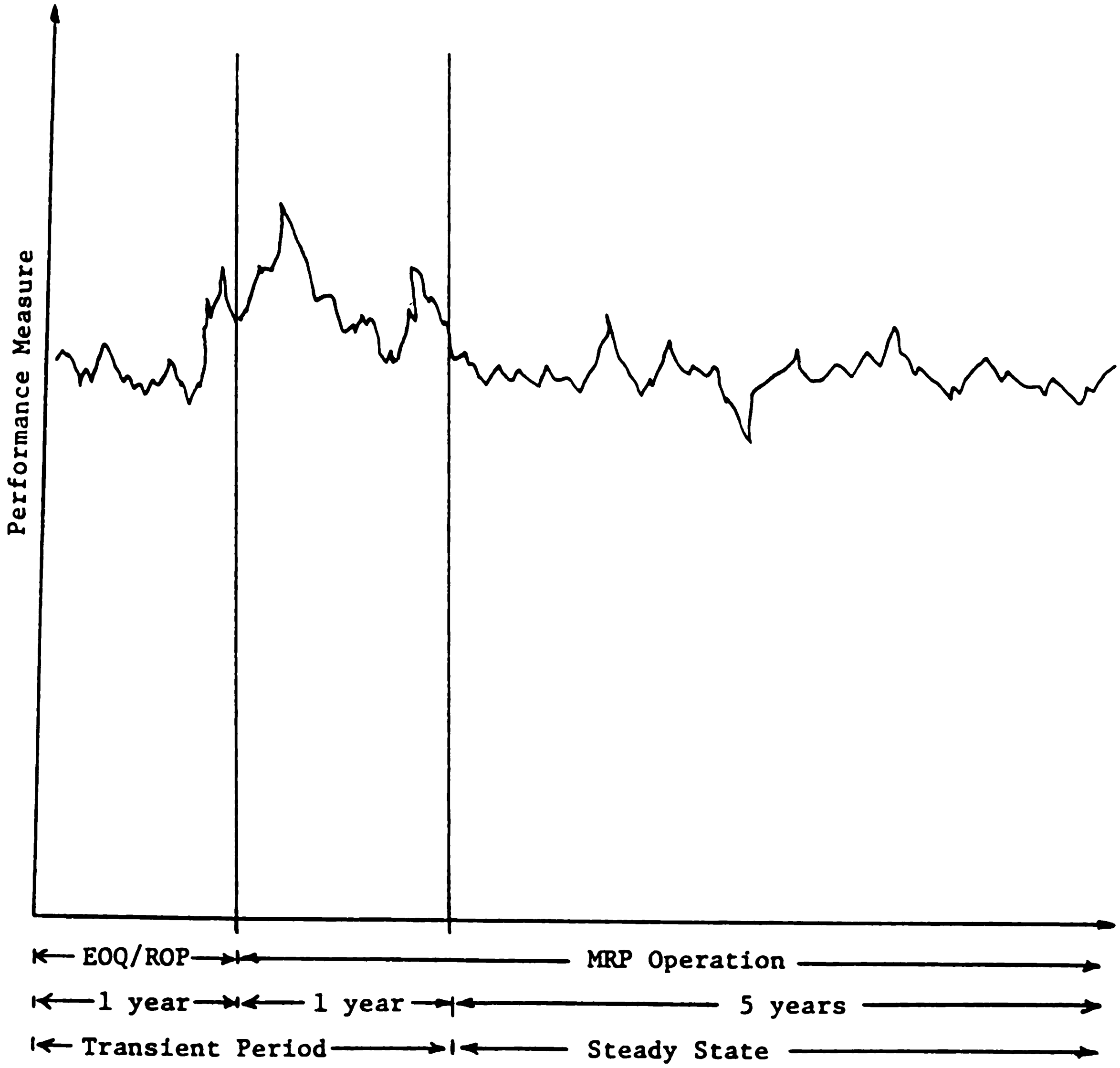


Figure 5.2 Data Collection of Simulation Experiment

starting condition, it is expected to be rather short. Shannon (1975) indicated that there is no foolproof method to determine when steady state conditions have been obtained, so the approach used to determine steady state condition is confirmed by testing the constant mean and variance of the performance measure, total related cost, over a period of time.

According to the plot of total related cost for 36 periods of 6 months' data as seen in Figure 5.3, the steady state seems to be reached after the first year of MRP operation. This time series plot of total related cost reveals that the spikes of low values which represent the long run nature of that time series occurs after the second year of simulation (Shannon, 1975). This visual inspection can be confirmed by a relatively constant mean over an extensive period of time. Therefore, the first two years of simulation run (one year of EOQ/ROP operation to load up the system and one year of MRP operation) are considered the initialization periods. Based on the batch size and sample size just determined, five years of monthly data (240 monthly data) were collected for each treatment in this research.

Validation

One important consideration for any simulation model is its validity, which can be defined as the process of determining how well the system replicates properties of some other system (Emshoff and Sisson, 1970). Validity affects ability to apply simulation results to real-world systems. This study must establish that the model does replicate the important attributes of actual multi-product, multi-state production system.

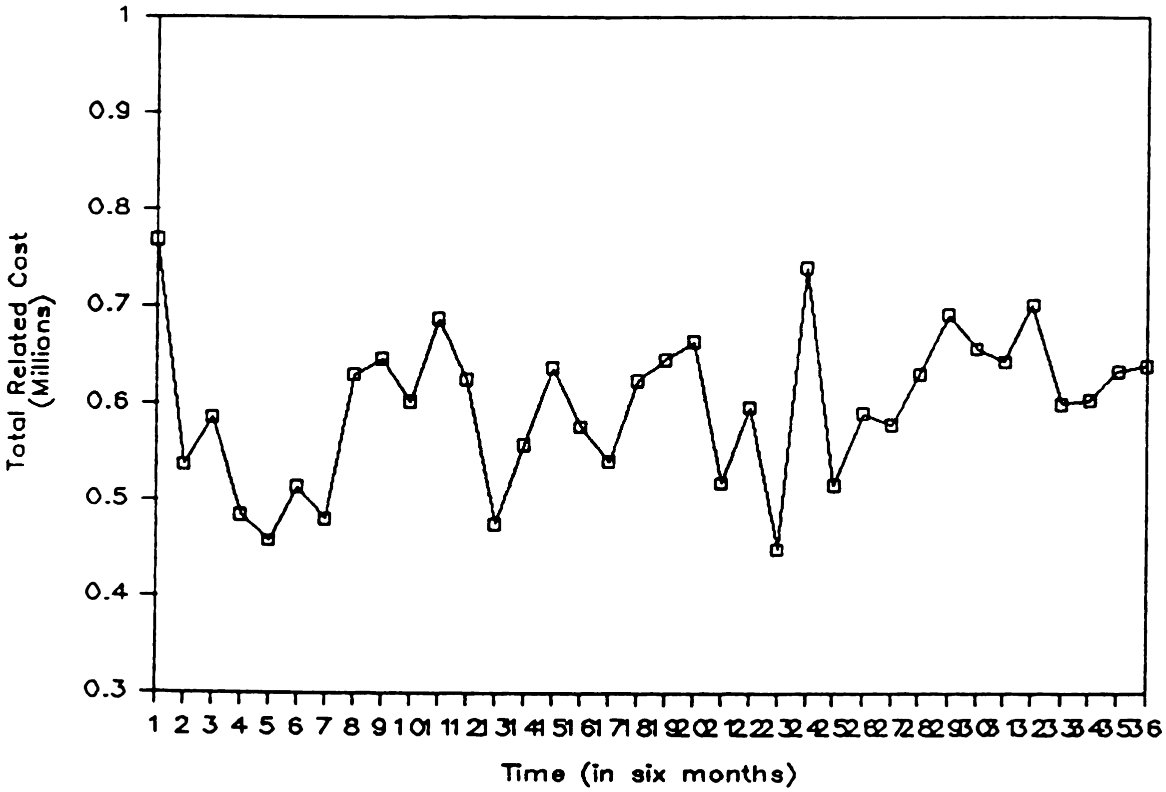


Figure 5.3 Time Series Plot of Total Related Cost

Emshoff and Sisson (1970, pp. 204-205) indicated that there are five preliminary approaches to validating simulation models:

1. Internal validity: In order to achieve internal validity, it requires low variability of outputs because a stochastic model with a high variance owing to internal process will obscure changes in output resulting from changes in controlled or environmental variables.

2. Face validity: This is the initial impression of a simulation model and can be obtained by asking the people who know the real world system to judge whether the model is reasonable.

3. Variable-parameter validity: Sensitivity testing is a form of variable-parameter validity. In a sensitivity test, one or more factors are changed to determine if they affect the output.

4. Hypothesis validity: Whether the pairwise relationships of the experimental factors in the model correspond to similar relationships in the observable universe is the main concern in this validity test.

5. Event or time-series validity: In this test, it is required to establish the credibility of a simulation model to predict observable events, event patterns, or variation in output variable.

In this study, it is managed to go through tests 1 through 4 to assure that this model is worth using for further research or decision aiding. For the internal validity, it was found that high variance of output variables does exist in some operating conditions. A logarithmic transformation is applied to stablize the variance. The data transformation will be discussed in detail in Chapter Six. The operating characteristics such as production routing or manufacturing lead time, are derived from a realistic case: NATCO job shop (Berry and Whybark, 1972). Therefore, face validity can be demonstrated through examining the model's operating characteristics, which are discussed in Chapter Four.

In order to obtain variable-parameter validity and hypothesis validity, several trial runs with simulation length of 75 weeks of operation were used to validate this simulated factory. First, an MRP system with rescheduling capability was compared with one without rescheduling capability in an operating condition characterized by the low capacity utilization, the low uncertainty level and L4L lot-sizing rule. It was found that the MRP system with rescheduling capability performed better than the one without rescheduling capability in terms of the total related cost. The average monthly total related cost for the case without rescheduling capability is $907,909, which is compared with $887,467 for the case with rescheduling capability. Secondly, a simulated factory with uncertain events are compared with that without uncertain events. The average monthly total related cost for the case without uncertain events is $874,909, which is lower than $905,275 for the case with uncertain events in an operating condition in which L4L and the static dampening procedure are used, and the capacity utilization is low. The preliminary results also conformed to the expectation that the occurrence of uncertain events would drive up the total related cost because of additional efforts or costs required to deal with these uncertain events.

Hypothesis Statement

The research questions address two main issues: (1) the effectiveness of the dampening procedures; and (2) the effect of operating conditions in the manufacturing environment on the relative effectiveness of the dampening procedures. These issues lead to the formulation of hypotheses described in this section followed by the rationale underlying the hypotheses.

The experimental design for this project involves four factors; so it is necessary to determine whether or not there are any significant interactions between the factors because significant interactions can influence the additivity of factor effects (Neter & Wesserman, 1975, pp. 588-589). Although the high order interaction effects are difficult to interpret, they provide some insights into interesting issues. For instance, the dynamic lot-sizing rule, high uncertainty level and the cost-based dampening procedure should have a very interesting interaction effect. In terms of the degree of system nervousness, dynamic lot sizing rules and high uncertainty level create a high degree of system nervousness while the cost-based dampening procedure dampens system nervousness. Consequently, it is interesting to investigate this interaction effect.

Specifically, there should be six hypotheses for two-factor interactions. However, because the main concern in this study is the dampening procedure, only three two-factor interaction hypotheses are presented (see Table 5.3). Then, the hypotheses of main effects are summarized in Table 5.4. Also included are "a priori" knowledge, expected result, and contribution in each table.

Table 5.3 Hypotheses of Interaction Effects

Hypothesis	"A priori"	Expected Result	Significant Contribution
1. The interaction effect between dampening procedure and uncertainty is insignificant in terms of the total related cost	A more comprehensive dampening procedure is required for a production system with a higher uncertainty level	Rejected	Planners can determine which dampening procedure is best appropriate for the uncertain situation they encounter
2. The interaction effect between dampening procedure and capacity level is insignificant in terms of the total related cost	When there is sufficient slack capacity, the performance of all the dampening procedures tends to converge	Rejected	Planners can determine which dampening procedure is suitable for their capacity level
3. The interaction effect between dampening procedure and lot-sizing rule is insignificant in terms of the total related cost	A dynamic lot-sizing rule tends to cause higher degree of MRP system nervousness which requires a cost-based dampening procedure to reduce the cost	Rejected	Planners can determine which dampening procedure is suitable for the degree of MRP system nervousness caused by a certain dynamic lot-sizing rule

Table 5.4 Hypotheses of Main Effects

	Hypothesis	"A priori"	Expected Result	Significant Contribution
1.	The performance of any dampening procedure is not different from that of any other dampening procedure tested in terms of the total related cost	A more comprehensive dampening procedure tends to consider more information which leads to a better system performance	Rejected	Planners can identify the best dampening procedure if ther are no significant interaction effects
2.	The performance of using L4L is not different from that of EOQ in terms of the total related cost	Many researchers claim that dynamic lot-sizing rules perform better than static lot-sizing rules	Rejected	MRP users can use a dynamic lot-sizing rule because it produces a better overall system performance, measured by the total related cost
3.	There is no significant impact of uncertainty level on the total related cost	Higher degree of uncertainty tends to disrupt production more frequently which incurs extra administration cost	Rejected	Managers should recognize their own production uncertainty and know the methods available to deal with uncertainty
4.	There is no significant impact of capacity utilization level on the total related cost	It is believed that slack capacity is one means to deal with production uncertainty	Rejected	Different capacity utilization level leads to different level of system performance

The most important hypothesis in Table 5.4 is related to whether or not there is significant difference in the performance of alternative dampening procedures. This research proposes that the selection of a dampening procedure have a significant impact on system performance. However, if significant interaction effects exist, the main effect of dampening procedures cannot be examined individually. Therefore, further exploition of the performance effectiveness of alternative dampening procedures under various operating conditions is justified. The following hypotheses are formulated to address the research questions defined previously.

Hypotheses 1: In a production environment typified by a given set of operting conditions under study, there is no significant difference among these three dampenng procedures in terms of total related cost.

Increased information in the design of dampening procedure is expected to improve the performance of production system. It should be noted that there are 8 operating conditions simulated, so there should be 8 similar hypotheses of this type. Within the context of the value of information, the cost-based dampening procedure should improve the system performance. The following are the formal statements of this set of hypotheses.

$$H_0 : TC_{1...} = TC_{2...} = TC_{3...}$$

$$H_1 : TC_{1...} \neq TC_{2...} \neq TC_{3...}$$

Where $TC_{i...}$ represents the total related cost generated by the ith dampening procedure in a certain operating condition

H_0 represents the null hypothesis and H_1 represents the alternative hypothesis

Hypotheses 2: Under the condition of low capacity utilization level, the performance of three dampening procedures tested tends to converge, while the more comprehensive dampening procedure tends to perform well under the high capacity utilization level.

It is believed that the uncommitted capacity is one way to deal with production uncertainty. The relative performance of one dampening procedure is not expected to be distinguished from the other. When the capacity utilization rate is high, system flexibility declines. The performance of the static dampening procedures and automatic rescheduling procedure may deteriorate under this condition, because of their dependence on the presence of system flexibility. The relative effectiveness of alternative dampening procedures may be detected under the high capacity utilization level. The following are the formal statements of hypotheses 2. Based on the previous argument, this set of hypotheses is expected to be rejected under the high capacity utilization level; and to be accepted under the low capacity utilization level. The formal statements are presented as follows.

For low capacity level:

$$H_0 : TC_{1..L} = TC_{2..L} = TC_{3..L}$$

$$H_1 : TC_{1..L} \neq TC_{2..L} \neq TC_{3..L}$$

For high capacity level:

$$H_0 : TC_{1..H} = TC_{2..H} = TC_{3..H}$$

$$H_1 : TC_{1..H} \neq TC_{2..H} \neq TC_{3..H}$$

Where $TC_{i..j}$ represents the total related cost generated by the ith dampening procedure in the operating conditions associated with jth level of capacity

Hypothesis 3A: The use of dynamic lot sizing rule does cause a higher degree of MRP system nervousness.

Hypothesis 3B: The use of dynamic lot sizing rule improves the total related cost.

For this set of hypotheses, a secondary performance measure--degree of MRP system nervousness--is used as another performance measure. Many practitioners, such as Peterson (1975), considered the use of dynamic lot-sizing techniques as the cause of MRP system nervousness. Hypothesis 3A is formulated to confirm this claim. However, hypothesis 3B also intends to test that the overall performance, total related cost is improved by using dynamic lot-sizing rules. That is, MRP system nervousness is not a necessary evil--it only reflects the degree of uncertainty encountered in a production system. The formal statements are presented as follows.

For total related cost:

$$H_0 : TC_{.L..} \leq TC_{.E..}$$

$$H_1 : TC_{.L..} > TC_{.E..}$$

For system nervousness:

$$H_0 : SN_{.L..} \geq SN_{.E..}$$

$$H_1 : SN_{.L..} < SN_{.E..}$$

Where $TC_{.i..}$ represents the total related cost generated by the use of a a lot-sizing rule and $SN_{.i..}$ represents the system nervousness caused by using a certain lot-sizing rule

Statistical Analysis

The statistical method used in this research is analysis of variance (ANOVA). ANOVA is used to analyze the effect of the independent variables on the system performance measures. It is concerned with statistical relations between independent and dependent variables (Neter

& Wasserman, 1974, pp. 419-420).

F-test

F-test is used to determine whether the production design factors have significant impact on the performance measures. The significance level is set at 0.05 in the data analysis, if not specified otherwise. If the null hypothesis is accepted, then it can tentatively be concluded that the sample difference between factors or interaction effects is attributable to random fluctuation instead of a real differences in population means. If the null hypothesis is rejected, one should determine whether it can be attributed to either the main effect or interaction effect. Then, futher analysis, such as multiple comparison or multiple ranking, is recommended (Naylor, 1971, p. 201).

Multiple Comparison Method

The least significance difference (LSD) test is the multiple comparison procedure used in this study (Kirk, 1982). This test consists of first performing a test of the overall null hypothesis that all the factor level means are equal by means of an F statistic. If the overall null hypothesis is rejected, multiple t statistics are used to evaluate all pairwise comparisons among means. If the overall F statistic is not significant, no further test are performed. If the F statistic is significant, the least significant difference between two means is

$$\Psi(\text{LSD}) = t_{\alpha/2,\nu}\sqrt{\frac{2 * MS_{error}}{n}}$$

where $t_{\alpha/2}$ is the upper $\alpha/2$ percent point from Student's t distribution and ν is the degree of freedom associated with MS_{error}, the denominator of the F statistic (Kirk, 1982, p. 115)

If the absolute value of a comparison exceeds the least significant difference calculated, the comparison is declared significant. Kirk (1982) also indicated that this procedure is convenient if the sample sizes are equal because the least significant difference between two means needs only be calculated once for any set of comparisons.

Multiple Ranking

One of the research objectives of the present study is to compare the effectiveness of these three dampening procedures under various operating conditions. A multiple ranking procedure is a direct approach to achieving this objective (Naylor, 1971, p. 205). Naylor indicated that the best ranking method for a set of alternatives is simply the ranking of sample means. However, simple ranking may yield incorrect results due to randomness. Therefore, a multiple ranking procedure is designed to construct a rinking which represent the true ranking of population means (Naylor, 1971, p. 205).

Summary of Chapter Five

The full factorial design was presented along with the justification of the factors included in the experimental design in this chapter. Several tactical aspects of simulation were also discussed. The hypotheses were stated and the statistical methods used to analyze the experimental results were briefly justified. The next chapter will present the experimental results and provide major findings stemming from the results.

CHAPTER SIX

DATA ANALYSIS AND RESULTS

The purpose of this chapter is to present the data gathered from the simulation experiment that was designed to evaluate the effectiveness of alternative dampening procedures for coping with MRP system nervousness. The results and data analysis concerned with the general effects are presented first. Then, the data analysis is presented with regard to the relative performance of these dampening procedures under operating conditions characterized by lot-sizing rule used, uncertainty level occurred, and capacity level utilized. The effects of operating conditions upon the relative performance of these dampening procedures are then evaluated. Finally, guidelines stemming from the data analysis are proposed to help material planners select an appropriate dampening procedure to cope with MRP system nervousness.

The means and standard deviations for the total related cost and the finished goods tardiness are presented in Tables 6.1 and 6.2. Each mean and standard deviation was based on a sample of ten observations that were collected using batch sampling. The basic assumptions of the ANOVA model used to analyze the data for hypothesis testing are that the data within a treatment population are independent and normally distributed and that the data accross populations that are compared have homogeneous variance. A one-period lag correlation coefficient was used to test

Table 6.1 Total Related Cost

			Low Uncertainty			High Uncertanity		
CL	LS	Total Related Cost	Static DP	Automatic RP	Cost-based DP	Static DP	Automatic RP	Cost-based DP
Low	L4L	μ	901,548	893,817	870,327	937,799	808,123	882,794
		σ	114,667	96,975	84,695	525,316	228,065	245,463
	EOQ	μ	824,170	868,133	766,218	786,474	920,321	735,457
		σ	229,505	130,839	101,106	255,025	267,355	158,006
High	L4L	μ	1,227,331	1,325,807	1,258,278	1,798,658	1,623,516	1,616,716
		σ	298,945	341,501	295,950	227,403	357,719	223,432
	EOQ	μ	1,677,241	1,743,913	1,563,793	2,404,989	3,991,297	2,170,272
		σ	490,368	246,285	392,700	420,100	1,461,958	232,331

Table 6.2 Finished Goods Tardiness

			Low Uncertainty			High Uncertanity		
CL	LS	Finished Goods Tardiness	Static DP	Automatic RP	Cost-based DP	Static DP	Automatic RP	Cost-based DP
Low	L4L	μ	9.629	9.849	6.332	14.67	16.376	21.181
		σ	4.69	4.92	4.35	9.61	17.23	9.60
	EOQ	μ	43.103	76.592	39.894	67.187	131.972	72.355
		σ	25.49	40.57	24.28	54.74	71.16	71.0
High	L4L	μ	77.218	128.434	84.65	202.985	166.727	170.631
		σ	40.01	55.68	36.40	35.27	45.24	46.78
	EOQ	μ	304.123	332.958	260.075	516.828	1,261.209	463.887
		σ	60.51	104.93	95.42	107.55	413.06	60.73

independence assumption while the Shapiro-Wilk statistic, W, was computed to check normality assumption.

The one-period lag correlation coefficients that were calculated for the total related cost and finished goods tardiness are presented in Table 6.3, in which TRC represents the total related cost and FGT represents the finished goods tardiness. Also, D1 represents the static dampening procedure, D2 represents the automatic rescheduling procedure, and D3 represents the cost-based dampening procedure in the following tables. In order to be significantly different from zero at .05 level of significance, the absolute value of a given one-period lag correlation coefficient must be greater than 0.66 (Clark and Schkade, 1969, p.569). Inspection of the figures presented in Table 6.3 revealed that none of coefficients calculated for the total related cost exceeded this critical value. One of the twenty-four coefficients calculated for the finished goods tardiness exceeded this critical value. Thus, the observations within each treatment population were considered to be independent.

The Shapiro-Wilk statistic, W, tabulated in Table 6.4 in terms of the total related cost and finished goods tardiness revealed that the normality assumption was not violated in all the treatment populations. According to SAS guide (1982), when p is less than 0.01 it is considered as the violation of normality assumption at .01 level of significance. However, when the Bartlett test was used to test the assumption of homogeneous variance, the result shown in Table 6.5 indicates that this assumption was violated.

Neter and Wasserman (1975) suggested that three different cases be considered for stabilizing the variances: (1) variance proportional to

Table 6.3 Results of Testing Independence Assumption

CAP	LS	Statistic	Low Uncertainty D1	Low Uncertainty D2	Low Uncertainty D3	High Uncertainty D1	High Uncertainty D2	High Uncertainty D3
Low	L4L	TRC	.259	.057	-.181	-.163	-.153	-.192
		FGT	.122	-.264	-.393	-.242	-.207	-.505
	EOQ	TRC	-.40	.153	-.181	-.248	-.165	.215
		FGT	.157	-.256	-.393	-.297	-.326	-.346
High	L4L	TRC	-.152	.074	-.338	-.193	-.485	.012
		FGT	-.859	-.097	-.318	.123	-.163	.350
	EOQ	TRC	-.103	.136	-.142	.043	-.436	-.183
		FGT	-.132	-.175	-.421	.103	-.089	.175

Table 6.4 Results of Testing Normality Assumption

				Low Uncertainty			High Uncertainty		
CAP	LS	Statistic		D1	D2	D3	D1	D2	D3
Low	L4L	TRC	W	.979	.937	.889	.573	.889	.756
			p < W	.956	.494	.278	.01	.216	.01
		FGT	W	.986	.882	.961	.908	.806	.938
			p < W	.999	.174	.771	.328	.02	.499
	EOQ	TRC	W	.832	.928	.941	.840	.961	.942
			p < W	.041	.443	.541	.048	.769	.548
		FGT	W	.945	.955	.921	.901	.969	.791
			p < W	.587	.697	.402	.285	.864	.013
High	L4L	TRC	W	.874	.962	.816	.829	.823	.963
			p < W	.131	.776	.028	.038	.034	.791
		FGT	W	.867	.934	.900	.940	.919	.932
			p < W	.097	.476	.280	.518	.389	.466
	EOQ	TRC	W	.908	.958	.985	.830	.904	.947
			p < W	.324	.738	.989	.039	.302	.601
		FGT	W	.923	.887	.966	.955	.936	.908
			p < W	.416	.203	.832	.699	.486	.327

Table 6.5 Results of Testing Homogeneous Variance Assumption

Performance Measure	Bartlett's Box F	p
Total Related Cost	25.125	0.0
Finished Goods Tardiness	48.905	0.0

the factor level mean, (2) standard deviation proportional to the factor level mean, and (3) standard deviation proportional to the square of factor level mean (p. 507). If case (1) exists, a square root transformation is helpful for stabilizing the variances. A useful transformation in case (2) is logarithmic transformation, while an appropriate transformation in case (3) is reciprocal transformation.

In order to detect the relationship between the variance (or standard deviation) and the factor level mean, a simple regression was run for each case in terms of the total related cost and finished goods tardiness. The R squared and adjusted R squared for these three cases are tabulated in Table 6.6. Case (2) has the highest R squared among these three cases considered, so the logarithmic transformation was performed for the data collected on which the data analysis is based. After the logarithmic transformation was performed on the total related cost and finished goods tardiness, the assumption of homogeneous variance was met. The Bartlett's Box F was 2.722 ($p = 0.066$) for the total related cost, and 0.507 ($p = 0.602$) for the finished goods tardiness. The mean and standard deviaiton for the transformed total related cost and finished goods tardiness are presented in Tables 6.7 and 6.8 respectively. In the following section, an ANOVA is performed by using these transformed data.

General Effects

It is the intention of this study to evaluate the null hypothesis that none of the factors selected significantly affects the system performance. Also, this study is interested in determining whether or not there are any significanct interactions present between the

Table 6.6 Proportionality test of Data Transformation

Performance Measure	Case	R^2	Adjusted R^2
Total Related Cost	μ vs δ^2	0.0027	-.0426
	μ vs δ	.4257	.3996
	μ^2 vs δ	.2909	.2587
Finished Goods Tardiness	μ vs δ^2	.1657	.1278
	μ vs δ	.5209	.4991
	μ^2 vs δ	.1534	.1149

Table 6.7 Total Related Cost with Logarithmic Transformation

			Low Uncertainty			High Uncertanity		
CL	LS		Static DP	Automatic DP	Cost-based DP	Static DP	Automatic DP	Cost-based DP
Low	L4L	μ	13.70	13.70	13.67	13.66	13.57	13.66
		σ	0.13	0.11	0.10	0.39	0.27	0.24
	EOQ	μ	13.59	13.66	13.54	13.53	13.69	13.99
		σ	0.25	0.15	0.14	0.30	0.29	0.22
High	L4L	μ	14.0	14.07	14.02	14.4	14.28	14.32
		σ	0.23	0.25	0.22	0.12	0.21	0.14
	EOQ	μ	14.3	14.36	14.23	14.68	15.13	14.59
		σ	0.28	0.14	0.27	0.16	0.41	0.11

Table 6.8 Finished Goods Tardiness with Logarithmic Transformation

			Low Uncertainty			High Uncertanity		
CL	LS		Static DP	Automatic DP	Cost-based DP	Static DP	Automatic DP	Cost-based DP
Low	L4L	μ	2.06	2.05	1.5	2.44	2.25	2.9
		σ	0.86	0.9	1.03	0.82	1.22	0.5
	EOQ	μ	3.5	4.25	3.42	3.78	4.7	3.89
		σ	0.94	0.56	0.89	1.08	0.72	0.95
High	L4L	μ	4.24	4.76	4.36	5.3	5.08	5.11
		σ	0.48	0.46	0.4	0.18	0.27	0.26
	EOQ	μ	5.7	5.77	5.49	6.23	7.07	6.13
		σ	0.21	0.29	0.42	0.21	0.46	0.14

experimental factors themselves. In other words, the null hypothesis is that none of the experimental factors interacts with each other.

To test the main effects and interaction effects of experimental factors, two 3x2x2x2 (dampening procedure x lot-sizing rule x uncertainty level x capacity utilization level) ANOVA models were performed, in which the total related cost and the finished goods tardiness were used as the performance measures respectively. The results of these two ANOVA runs are tabulated in Table 6.9.

As shown in Table 6.9, all the main effects were found to be significant in terms of the total related cost and the finished goods tardiness at .05 level of significance. The interaction effects between dampening procedure and lot-sizing rule ($F = 7.82$, $p < 0.0005$), lot-sizing rule and capacity utilization level ($F = 56.0$, $p < 0.0001$), and uncertainty level and capacity utilization level ($F = 56.84$, $p < 0.0001$) were found to be significant in terms of the total related cost. One second-order interaction effect, dampening procedure, lot-sizing rule and uncertainty levle ($F = 4.20$, $p < 0.0162$) was also found to be significant in terms of the total related cost. None of the remaining first-order, second-order, or third-order interaction effects were statistically significant. A similar result regarding the interaction effects was found for the performance measure of finished goods tardiness. The significant interaction effects among the experimental factors strongly suggest that different dampening procedures may be required for best performance under different combinations of operating conditions, characterized by the lot-sizing rule, the uncertainty level and the capacity utilization level.

Table 6.9 Results of ANOVA

Source	Degree of Freedom	Total Related Cost			Finished Goods Tardiness		
		SS	F	P <	SS	F	P <
DP	2	0.56	5.37	0.0053	7.03	7.70	0.0006
LS	1	1.26	24.07	0.0001	132.12	289.46	0.0001
UL	1	1.94	36.85	0.0001	25.52	55.90	0.0001
CL	1	32.94	627.16	0.0001	337.54	739.54	0.0001
DP x LS	2	0.82	7.82	0.0005	5.46	5.98	0.003
DP x UL	2	0.05	0.52	0.5961	0.91	0.99	0.3716
DP x CL	2	0.12	1.16	0.3165	0.09	0.10	0.9081
LS x UL	1	0.20	3.72	0.0551	0.10	0.22	0.6419
LS x CL	1	2.94	56.0	0.0001	3.17	6.94	0.009
UL x CL	1	2.99	56.84	0.0001	0.77	1.70	0.1942
DP x LS x UL	2	0.44	4.20	0.0162	3.75	4.11	0.0177
DP x LS x CL	2	0.05	0.51	0.6032	1.10	1.20	0.3021
DP x UL x CL	2	0.08	0.77	0.4649	1.82	1.99	0.1389
LS x UL x CL	1	0.10	1.94	0.1647	0.58	1.27	0.2606
DP x LS x UL x CL	2	0.11	1.00	0.3688	1.29	1.41	0.2466

SSE = 11.344 SSE = 98.588

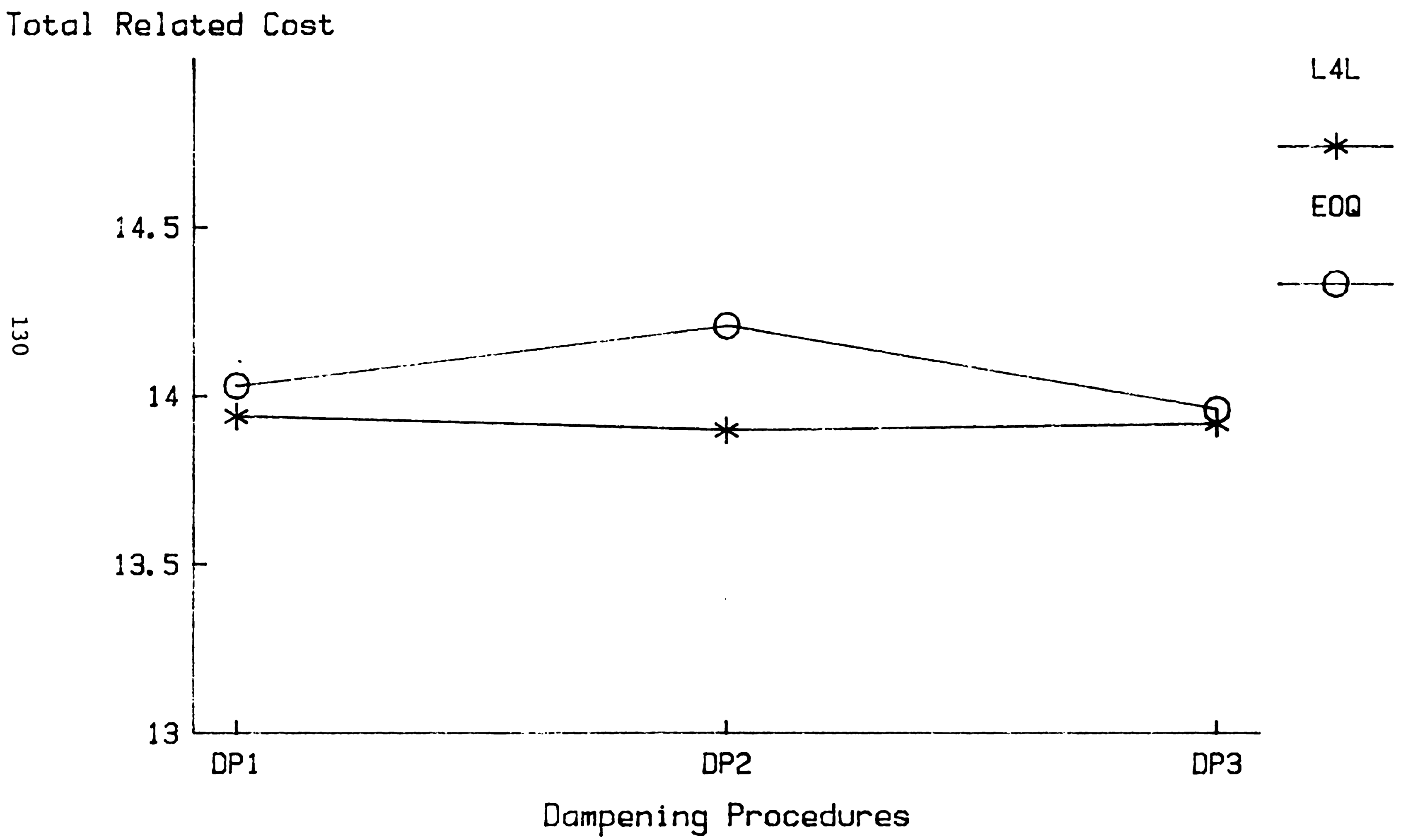
The interaction effects higher than second order may be difficult to interpret. Nevertheless, some interesting insights can be drawn from the significant first and second order interactions, particularly the interactions between the dampening procedure and the other experimental factors, which are discussed in the following section.

First-Order Interaction Effects

The first-order interaction effect between dampening procedure and lot-sizing rule is illustrated in Figure 6.1. It indicates that L4L lot-sizing rule generated the lower total related cost than EOQ lot-sizing rule regardless of which dampening procedure was used. Also, the difference, measured by the total related cost, between these two lot-sizing rules increases considerably when the automatic rescheduling procdure is used. This observation can be explained by the fact that the dampening procedures tested have different characteristics in terms of the manner in which the rescheduling messages are implemented. The automatic rescheduling procedure tends to implement all the rescheduling messages, while the static dampening procedure establishes a "no rescheduling fence" to screen out "insignificant" rescheduling messages. The cost-based dampening procedure falls somewhere between these two dampening procedures in terms of the number of rescheduling messages implemented. Therefore, the automatic rescheduling procedure tends to disrupt the production system more frequently than the cost-based and static dampening procedures.

For the lot-sizing rules tested, L4L tends to disrupt the system more frequently than EOQ in terms of the frequency of revising due dates for open orders. From the perspective of the disruption of production

Figure 6.1 Illustration of Significant First-order Interaction



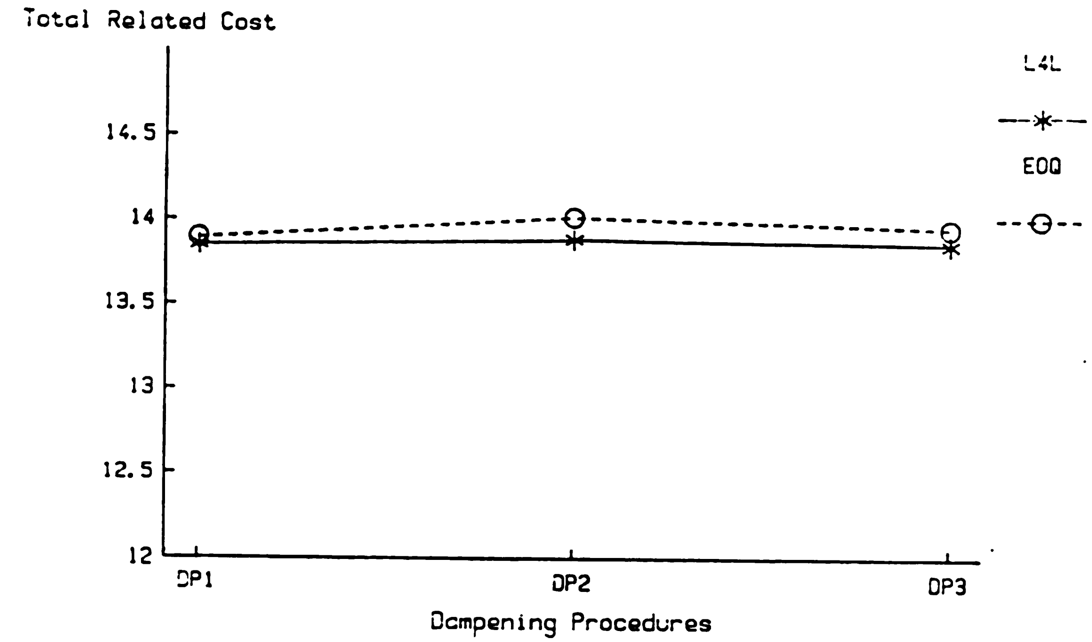
system, it is expected that the selection of lot-sizing rule would affect the selection of dampening procedure significantly.

Second-order Interaction Effect

Figure 6.2 illustrates the significant second-order interaction effect among the factors of dampening procedure, lot-sizing rule and uncertainty level in terms of the total related cost. In the operating conditions characterized by the low uncertainty level, the cost difference between L4L and EOQ lot-sizing rules was neglible for any dampening procedure used as seen in the top diagram in Figure 6.2. However, in the operating conditions characterized by the high uncertainty level, the cost difference between these two lot-sizing rules was significantly widened in the bottom diagram. This situation can be explained by the previous discussion that the responsiveness of lot-sizing rule and dampening procedure needs to be compatible in order for the production system to perform well. When using EOQ lot-sizing rule, the production system reacts to uncertain events slowly because the extra inventory carried with this lot-sizing rule. Therefore, the due dates for the final products are missed which drives up the shortage cost in the case of high uncertainty. This leads to the widening gap in the total related cost.

Relative Performance of Dampening Procedures

A one way ANOVA is performed for each operating condition in order to investigate the effectiveness of these dampening procedures for each operating condition, characterized by the lot-sizing rule, uncertainty



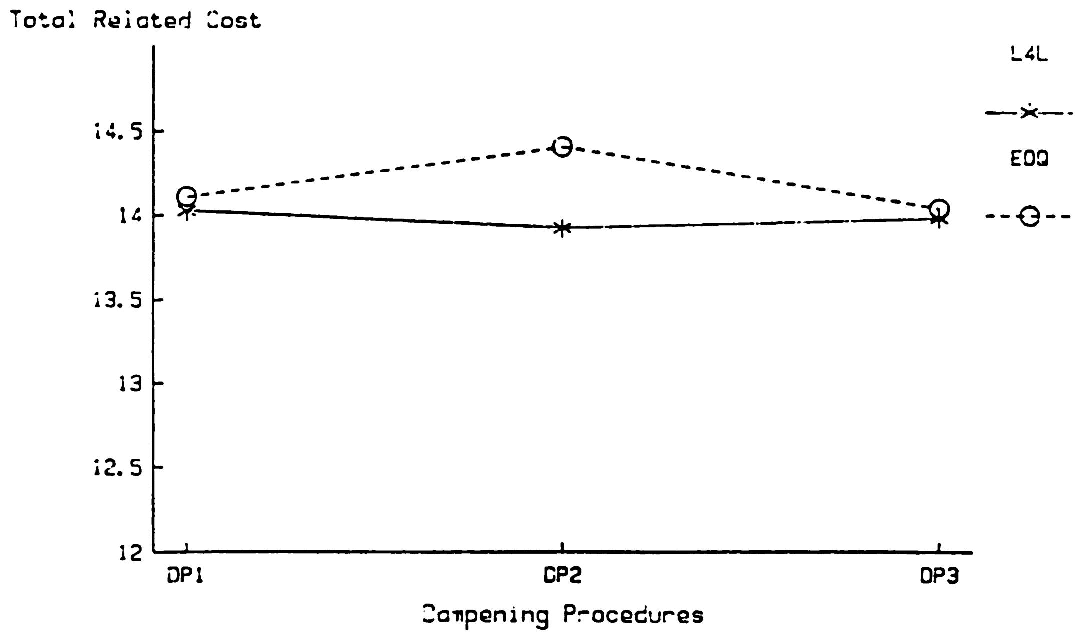


Figure 6.2 Illustration of Significant Second-order Interaction

level, and capacity utilization level. In this ANOVA model, the dampening procedure is the only independent variable. It is necessary to denote that the operating conditions are represented by the characters which indicate the levels in the order of experimental factors, lot-sizing rule, uncertainty level and capacity utilization level, respectively. For instance, LHH represents an operating condition in which L4L lot-sizing rule is used, high uncertainty level is encountered and high capacity level is utilized.

Total Related Cost

The results of applying least significant difference test are presented in Table 6.10 for the total related cost. The numerical ranking of the means of the total related cost is first established, which does not imply any statistical significance. The statistical significance is expressed in the pairwise comparisons that follow. LSD represents the least significant difference for a pairwise comparison to be considered significantly different. The performances of the three dampening procedures tested were not statistically significant under all the operating conditions with the exception of EHH. In EHH, the cost-based dampening procedure and the static dampening procedure outperformed the automatic rescheduling procedure significantly in terms of the total related cost. However, the total related cost generated by the cost-based dampening procedure and the static dampening procedure was not significantly different. These results can be partially attributed to the aggregation effect of the total related cost. Therefore, the components of the total related cost were further examined to evaluate these secondary performance measures of the

Table 6.10 Results of ANOVA by Total Related Cost

CAP	LS	Statistic	Low Uncertainty D1	Low Uncertainty D2	Low Uncertainty D3	High Uncertainty D1	High Uncertainty D2	High Uncertainty D3
Low	L4L	Ranking	3	2	1	3	1	2
		Mean	13.70	13.70	13.62	13.66	13.57	13.66
		D1 vs D2		N			N	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.1067			0.0937	
	EOQ	Ranking	2	3	1	2	3	1
		Mean	13.59	13.66	13.54	13.53	13.59	13.49
		D1 vs D2		N			N	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.1687			0.2497	
High	L4L	Ranking	1	3	2	3	1	2
		Mean	14.00	14.07	14.02	14.40	14.28	14.32
		D1 vs D2		N			N	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.2145			0.1451	
	EOQ	Ranking	2	3	1	2	3	1
		Mean	14.30	14.36	14.23	14.68	15.13	14.59
		D1 vs D2		N			Y	
		D1 vs D3		N			N	
		D2 vs D3		N			Y	
		LSD		0.2170			0.2418	

dampening procedures tested which will be presented in the next section. Nevertheless, the same result was reached in Penlesky's (1982) study. For the four dampening procedures tested (briefly described in Chapter Two) in one particular operating condition. Penlesky (1982) concluded that the relative performance of those four dampening procedures were not statistically significant in terms of total inventory level and customer service level at .05 level of significance.

Finished Goods Tardiness

In terms of the finished goods tardiness, the performance of the dampening procedures tested was significantly different in four of the eight operating conditions as shown in Table 6.11. In ELL, LLH. EHL. and EHH. the static dampening procedure and the cost-based dampening procedure were significantly better than the automatic rescheduling procedure at .05 level of significance. Furthermore. the results suggest that the use of EOQ lot-sizing rule with the automatic rescheduling procedure be avoided. Also, the result that the automatic rescheduling procedure performed as well as the cost-based dampening procedure and the static dampening procedure in LLL, LHL, LHH. and ELH in terms of the finished goods tardiness seems to imply that the automatic rescheduling procedure performed well with the use of L4L lot-sizing rule.

In ELL and EHH, the cost-based dampening procedure was ranked first in terms of the finished goods tardiness. This is probably due to the fact that EOQ lot-sizing rule tends to create a large lot size. If a large production lot needed to be rescheduled, it would amplify the magnitude of rescheduling decision, good or bad. The cost-based

Table 6.11 Results of ANOVA by Finished Goods Tardiness

CAP	LS	Statistic	Low Uncertainty D1	Low Uncertainty D2	Low Uncertainty D3	High Uncertainty D1	High Uncertainty D2	High Uncertainty D3
Low	L4L	Ranking	3	2	1	2	1	3
		Mean	2.057	2.046	1.504	2.436	2.251	2.953
		D1 vs D2		N			N	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.8557			0.8234	
	EOQ	Ranking	2	3	1	1	3	2
		Mean	3.499	4.248	3.418	3.777	4.700	3.886
		D1 vs D2		Y			Y	
		D1 vs D3		N			N	
		D2 vs D3		Y			N	
		LSD		0.7461			0.8516	
High	L4L	Ranking	1	3	2	3	1	2
		Mean	4.238	4.764	4.363	5.299	5.083	5.108
		D1 vs D2		Y			N	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.4112			0.2229	
	EOQ	Ranking	2	3	1	2	3	1
		Mean	5.698	5.768	5.489	6.228	7.066	6.131
		D1 vs D2		N			Y	
		D1 vs D3		N			N	
		D2 vs D3		N			Y	
		LSD		0.2943			0.2773	

dampening procedure was designed to make the most sensible rescheduling decision, so it performed very well because of this amplification effect.

In summary, the foregoing discussion provides some important results regarding the relative performance of alternative dampening procedures:

> In terms of the total related cost, there was no significant difference among the dampening procedures except EHH. Relative to the finished goods tardiness, there was no significant difference among the dampening procedures except ELL, LLH, EHL, and EHH. In those operating conditions that indicated statistical significance, the automatic rescheduling procedure was outperformed by the static dampening procedure and the cost-based dampening procedure.

It should be noted that the results and conclusions presented above apply to the operating conditions studied in this dissertation. The aggregation effect of the total related cost, which served as the primary performance measure, played an important role in reaching such a result. Therefore, two follow-up analyses were performed in order to better understand the underlying causes of relationship identified above.

Follow-up Analysis

The first follow-up analysis was to investigate the cost components of the total related cost in detail. That is, the shortage cost, set-up cost, and inventory carrying cost were examined for these three dampening procedures. The second follow-up analysis was to examine the difference in rescheduling decisions made by alternative dampening proceaure tested. One of the research hypotheses tested in this follow-up analysis was that the total related cost is not necessarily related to MRP system nervousness generated by a certain dampening procedure.

1. Cost components of Total Related Cost

The composition of the total related cost was examined in detail in this follow-up analysis. The ranking, statistical significance, and least significant difference are presented in Tables 6.12, 6.13, and 6.14 for the dampening procedures tested in terms of the shortage cost, inventory carrying cost and set-up cost respectively.

The reason that the cost-based dampening procedure did not perform significantly better than the other dampening procedures in terms of the total related cost was investigated first. In EHL and EHH, the cost-based dampening procedure performed significantly better than the automatic rescheduling procedure in terms of the shortage cost. However, the cost-based dampening procedure did not perform well, compared with the automatic rescheduling procedure, in terms of the set-up cost and inventory carrying cost. This situation can be explained by the fact that the cost-based dampening procedure is focused on the cost comparison of rescheduling decision which mainly involved the penalty cost of component shortage. Thus, the set-up cost and inventory carrying cost were not reduced significantly.

Due to this "mixed" performance in the cost composition of the total related cost, the relative performance among the dampening procedures were not significantly different in a majority of operating conditions. From the analysis of cost components, it is observed that there were four operating conditions in which the statistical significance existed among the dampening procedures in terms of the inventory carrying cost. In these four operating conditions, all characterized by high uncertainty level, the automatic rescheduling procedure performed quite well when comparing with the static and cost-based dampening procedures,

Table 6.12 Results of ANOVA by Shortage Cost

			Low Uncertainty			High Uncertainty		
CAP	LS	Statistic	D1	D2	D3	D1	D2	D3
Low	L4L	Ranking	2	3	1	1	2	3
		Mean	11.29	11.37	10.98	11.13	11.40	11.73
		D1 vs D2		N			N	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.9186			1.0557	
	EOQ	Ranking	2	3	1	2	3	1
		Mean	12.08	12.58	11.95	12.29	12.80	11.84
		D1 vs D2		N			N	
		D1 vs D3		N			N	
		D2 vs D3		N			Y	
		LSD		0.7468			0.6789	
High	L4L	Ranking	1	3	2	1	3	2
		Mean	12.96	12.58	13.07	13.70	13.49	13.51
		D1 vs D2		N			N	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.5130			0.2804	
	EOQ	Ranking	2	3	1	2	3	1
		Mean	13.79	13.89	13.67	14.29	14.72	14.16
		D1 vs D2		N			Y	
		D1 vs D3		N			N	
		D2 vs D3		N			Y	
		LSD		0.3258			0.3524	

Table 6.13 Results of ANOVA by Inventory Carrying Cost

CAP	LS	Statistic	Low Uncertainty D1	Low Uncertainty D2	Low Uncertainty D3	High Uncertainty D1	High Uncertainty D2	High Uncertainty D3
Low	L4L	Ranking	3	1	2	3	1	2
		Mean	12.03	12.02	12.02	12.40	12.03	12.29
		D1 vs D2		N			Y	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.2035			0.2627	
	EOQ	Ranking	1	2	3	2	1	3
		Mean	12.21	12.23	12.28	12.25	12.35	12.57
		D1 vs D2		N			N	
		D1 vs D3		N			Y	
		D2 vs D3		N			Y	
		LSD		0.0071			0.1714	
High	L4L	Ranking	3	1	2	2	1	3
		Mean	12.56	12.48	12.51	12.58	12.39	12.58
		D1 vs D2		N			Y	
		D1 vs D3		N			N	
		D2 vs D3		N			Y	
		LSD		0.1955			0.1302	
	EOQ	Ranking	2	3	1	2	3	1
		Mean	12.84	12.88	12.81	12.96	13.72	12.93
		D1 vs D2		N			Y	
		D1 vs D3		N			N	
		D2 vs D3		N			Y	
		LSD		0.0129			0.1035	

Table 6.14 Results of ANOVA by Set-up Cost

CAP	LS	Statistic	Low Uncertainty D1	Low Uncertainty D2	Low Uncertainty D3	High Uncertainty D1	High Uncertainty D2	High Uncertainty D3
Low	L4L	Ranking	2	1	3	2	1	3
		Mean	13.31	13.33	13.34	13.06	13.05	13.05
		D1 vs D2		N			N	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.0626			0.0692	
	EOQ	Ranking	2	1	3	2	1	3
		Mean	12.88	12.77	12.81	12.48	12.41	12.50
		D1 vs D2		N			N	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.0712			0.1084	
High	L4L	Ranking	2	1	3	3	2	1
		Mean	12.98	12.96	12.99	13.33	13.31	13.30
		D1 vs D2		N			N	
		D1 vs D3		N			N	
		D2 vs D3		N			N	
		LSD		0.0932			0.089	
	EOQ	Ranking	1	2	3	3	1	2
		Mean	12.43	12.43	12.47	12.74	12.30	12.70
		D1 vs D2		N			Y	
		D1 vs D3		N			N	
		D2 vs D3		N			Y	
		LSD		0.1368			0.1842	

except EHH. It appears that the automatic rescheduling procedure responded to more rescheduling messages, induced by the higher uncertainty level and L4L lot-sizing rule, to get the required order through the shop and into finished goods inventory. As a result, the work-in-process inventory was reduced. This result lends support to one of the major conclusions in Penlesky's (1982) study that the total inventory level of the dynamic dampening procedure improves relative to that of the "static" dampening procedure. Another observation can be made about the set-up cost. As shown in Table 6.14, the set-up cost generated by each dampening procedure was very similar when the means of set-up cost was examined in the eight operating conditions. Statistical significance in set-up cost was found in only one operating condition, EHH. This implies that the rescheduling decision determined by these dampening procedures have very little impact on the set-up cost.

2. Rescheduling Statistics

Tables 6.15 and 6.16 show the statistical analysis for the number of rescheduling messages and the number of rescheduling notices generated by these three dampening procedures. For all operating conditions tested, the rescheduling messages and rescheduling notices generated by the dampening procedures were significantly different. The cost-based dampening procedure generated the fewest number of rescheduling messages in all the operating conditions. The reason that the cost-based dampening procedure consistently generated fewer rescheduling messages than the automatic rescheduling messages may be due to the fact that the rescheduling messages generated within the minimum lead time should be rescheduled at the date of minimum lead time. This kind of rescheduling decision would prompt the MRP system to keep regenerating rescheduling

Table 6.15 Results of ANOVA by Number of Rescheduling Messages

			Low Uncertainty			High Uncertainty		
CAP	LS	Statistic	D1	D2	D3	D1	D2	D3
Low	L4L	Ranking	3	2	1	3	2	1
		Mean	4.522	3.931	3.857	4.487	4.003	3.956
		D1 vs D2		Y			Y	
		D1 vs D3		Y			Y	
		D2 vs D3		N			N	
		LSD		0.2503			0.1512	
	EOQ	Ranking	3	2	1	3	2	1
		Mean	2.932	2.515	2.099	3.202	2.446	2.192
		D1 vs D2		N			Y	
		D1 vs D3		Y			Y	
		D2 vs D3		N			N	
		LSD		0.6099			0.4607	
High	L4L	Ranking	3	2	1	3	2	1
		Mean	4.546	4.204	4.205	4.406	4.088	3.829
		D1 vs D2		Y			Y	
		D1 vs D3		Y			Y	
		D2 vs D3		N			Y	
		LSD		0.1875			0.1997	
	EOQ	Ranking	2	3	1	2	3	1
		Mean	3.243	3.446	2.570	3.180	3.769	1.852
		D1 vs D2		N			N	
		D1 vs D3		Y			Y	
		D2 vs D3		Y			Y	
		LSD		0.5105			0.5105	

Table 6.16 Results of ANOVA by Number of Rescheduling Notices

CAP	LS	Statistic	Low Uncertainty D1	Low Uncertainty D2	Low Uncertainty D3	High Uncertainty D1	High Uncertainty D2	High Uncertainty D3
Low	L4L	Ranking	1	3	2	1	3	2
		Mean	2.875	3.931	3.762	3.087	4.003	3.956
		D1 vs D2		Y			Y	
		D1 vs D3		Y			Y	
		D2 vs D3		N			N	
		LSD		0.2828			0.0356	
	EOQ	Ranking	1	3	2	1	3	2
		Mean	0.899	2.515	2.065	1.324	2.446	2.099
		D1 vs D2		Y			Y	
		D1 vs D3		Y			Y	
		D2 vs D3		N			N	
		LSD		0.3994			0.6107	
High	L4L	Ranking	1	3	2	1	3	2
		Mean	3.047	4.204	3.840	2.699	4.088	3.603
		D1 vs D2		Y			Y	
		D1 vs D3		Y			Y	
		D2 vs D3		Y			Y	
		LSD		0.2641			0.2614	
	EOQ	Ranking	1	3	2	1	3	2
		Mean	1.370	3.446	2.469	0.796	3.769	1.770
		D1 vs D2		Y			Y	
		D1 vs D3		Y			Y	
		D2 vs D3		Y			Y	
		LSD		0.5892			0.6727	

messages to move to the need date.

The automatic rescheduling procedure was ranked second under six out of the eight operating conditions according to this rescheduling statistic. In these two exceptional operating conditions, ELH and EHH, the static dampening procedure regenerated less rescheduling messages, which were screened out in the previous weeks, than did the automatic rescheduling procedure.

It should be noted that the number of rescheduling messages reflects the degree of uncertainty that exists within or outside the production system; it also reflects the difference in the decision mechanisms used in the dampening procedures. Therefore, the above analysis indicates that the cost-based dampening procedure dampens the rescheduling messages in a more effective manner, thus reducing the number of rescheduling messages generated in following weeks. The static dampening procedure screens out a lot of rescheduling messages which may subsequently be regenerated in the following weeks depending upon the offsetting effect of the common parts. As a result, material planners are burdened with more rescheduling messages to be analyzed.

The automatic rescheduling procedure has a similar situation when rescheduling messages are generated within the minimum lead time. These rescheduling messages would appear in the following week to request that the due dates should be changed to the need dates. Thus, the capability of the static dampening procedure and automatic rescheduling procedure for screening out unnecessary rescheduling messages is not as effective as that of cost-based dampening procedure.

In terms of the number of rescheduling notices, the static dampening procedure implemented the fewest rescheduling notices, followed by the cost-based dampening procedure and automatic rescheduling procedure. In general, the more rescheduling notices were implemented, the more frequently the shop priority was disrupted. As mentioned previously, the number of rescheduling notices can serve as a rough estimate of MRP system nervousness. Therefore, based on results presented in Table 6.16, the automatic rescheduling procedure creates the most nervous operating environment compared with the cost-based dampening procedure and static daampening procedure, while the static dampening procedure is by far effective in reducing system nervousness. However, a less nervous system does not mean better system performance. It is the appropriate rescheduling decision that makes the difference.

3. The Nature of Lot-sizing Rule

Hypotheses 3A and 3B stated in Chapter 5 referred to the impact of different nature of lot-sizing rule, namely static and dynamic, on MRP system nervousness and overall system performance. In this study, L4L was used to represent dynamic lot-sizing rule while EOQ represented static lot-sizing rule. One way ANOVA was used to analyze several performance measures, in which lot-sizing rule was the only independent variable. The results are summarized in Table 6.17. A significant difference was found in the number of rescheduling notices implemented generated by L4L and EOQ. The number of rescheduling notices roughly approximates the degree of system nervousness, which indicates the frequency with which order priority is disrupted. As indicated previously, the number of rescheduling notices are used to measure the post-dampening system nervousness operationally. Thus, it is concluded that the null hypothesis (that the use of dynamic lot-sizing rule does

Table 6.17 Results of ANOVA for The Nature of Lot-sizing Rule

	Total Related Cost			Finished Goods Tardiness			Number of Rescheduling Notices		
	Sig	Least Sig Diff	Mean	Sig	Least Sig Diff	Mean	Sig	Least Sig Diff	Mean
L4L	Y	0.1219	13.921	Y	0.3641	3.5083	Y	0.2202	3.5822
EOQ	Y		14.067	Y		4.9922	Y		2.0915

cause a higher degree of MRP system nervousness) cannot be rejected at .05 level of significance.

However, the total related cost generated by these two lot-sizing rules is significantly different. The null hypothesis (that the use of dynamic lot-sizing rule improves the overall system performance) cannot be rejected at .05 level of significance. An interesting fact that emerges from this hypothesis is that the dynamic lot-sizing rule is a more cost-effective lot-sizing rule in terms of the total related cost. Although the dynamic lot-sizing rule tested, L4L, could cause a higher degree of system nervousness than the static lot-sizing rule, as reflected by the larger number of rescheduling notices, its overall performance actually was better than that of the static lot-sizing rule.

Without investigating more lot-sizing rules, it is not appropriate to generalize that all dynamic lot-sizing rules would always outperform the static lot-sizing rules. L4L is a "conservative" lot-sizing rule which typically affects the production lot on a one-to-one basis with an uncertain event. Some other dynamic lot-sizing rule, such as periodic order quantity, may affect a series of planned order releases due to an uncertain event. Consequently, this change may have important effect on the scheduling of the lower-level items. Also, from the previous analysis, it appears that the selection of lot-sizing rules certainly affects the relative performance of dampening procedures tested. The performance of dampening procedures converges when a more effective lot-sizing rule is used. In the operating conditions associated with the use of EOQ, the considerable cost improvement is generated by the cost-based dampening procedure. Once again, with the limited number of lot-sizing rules tested, it is not sufficient to conclude that the selection of lot-sizing rule dominates the selection of dampening procedure. Nevertheless, the result obtained from this study certainly points out an interesting research direction which intends to investigate the relationship among MRP system nervousness, overall system performance, dampening procedures, and lot-sizing rules.

Within the context of this simulation experiment, the foregoing discussion provides some important insights regarding the use of dampening procedures.

1. Since the effectiveness of any one of the dampening procedures could not be statistically distinguished from that of any other procedure in terms of the total related cost in most of the operating conditions tested, it appears that material planners can select any dampening procedure that is suitable in their operating conditions. Some other decision criteria may play an important role in the selection process. The decision criterion might be the cost of developing the information required in a certain dampening procedure, the relative ease with which a certain dampening procedure might be implemented, or other secondary performance measures.

2. In terms of the finished goods tardiness, there are four operating conditions in which there was a significant difference of dampening procedures tested. If a company has a similar operating characteristics to these operating conditions identified, the cost-based dampening procedure or the static dampening procedure would be appropriate to cope with MRP system nervousness.

3. When looking into the cost components of the total related cost generated by the dampening procedures, there was almost no difference in the set-up cost, and some difference was observed in the inventory carrying cost and shortage cost. This implies that, for companies which emphasize the shortage cost or customer service level, the cost-based dampening procedure is the best alternative in the operating conditions for which statistical significance exists.

4. When examining the number of rescheduling messages and rescheduling notices, the rescheduling behavior among the dampening procedures were significantly different. The cost-based dampening procedure tends to screen out the rescheduling messages in such an effective manner that the number of rescheduling message is significantly reduced in the following weeks. The automatic rescheduling procedure tends to disrupt the system because a large number of rescheuling notices are implemented on the shop floor. As a result, the system performance does indeed deteriorate. Nevertheless, the static dampening procedure disrupts the shop priority the least, but the static dampening procedure is certainly not the best dampening procedure in terms of other performance measures.

Impact of Operating Conditions on the Relative Performance of Alternative Dampening Procedures Tested

In the preceding discussion, it became apparent that operating conditions have an important impact on the relative performance of dampening procedures tested. In order to investigate this impact, a 2x2x2 (lot-sizing rule x uncertainty level x capacity utilization level) ANOVA was performed for each dampening procedure in terms of the total related cost and other secondary performance measures. The analysis is conducted in order to evaluate the impact of operating conditions upon the relative performance of the dampening procedures tested, and identify those operating conditions in which a given dampening procedure can provide the greatest benefit. The impact of operating conditions will be presented for each dampening procedure.

Static Dampening Procedure

1. Total Related Cost

Tables 6.18 and 6.19 present the results of univariate F-test for the performance measures. The main effects of uncertainty level ($F = 9.54$, $p < 0.0029$), and capacity utilization level ($F = 168.96$, $p < 0.0001$) are found to be significant. This result indicated that the factor of capacity utilization level exerts an influence on the performance of the static dampening procedure. The interaction effect between the lot-sizing rule and uncertainty level ($F = 0.03$, $p = 0.8747$) was found to be insignificant, while those between the lot-sizing rule and capacity utilization level ($F = 14.02$, $p < 0.0004$), and uncertainty level and capacity utilization level ($F = 15.96$, $p < 0.0002$) were found to be

Table 6.18 Impact of Operating Conditions on Cost-related Measures Of Static Dampening Procedure

			Performance Measure			
Effect	degree of freedom	Statistic	Total Related Cost	Shortage Cost	Inventory Carrying Cost	Set-up cost
LS	1	F	2.40	21.09	21.76	797.0
		P	0.1254	0.0001	0.0001	0.0001
UL	1	F	9.54	3.08	15.20	0.28
		P	0.0029	0.0833	0.0002	0.5992
CL	1	F	168.96	117.67	131.0	6.11
		P	0.0001	0.0001	0.0001	0.0158
LSxUL	1	F	0.03	0.03	0.42	0.32
		P	0.8747	0.8545	0.518	0.5713
LSxCL	1	F	14.02	0.52	9.80	0.0
		P	0.0004	0.4735	0.0025	0.9696
ULxCL	1	F	15.96	2.56	4.60	235.53
		P	0.0002	0.114	0.0354	0.0001
LSxULxCL	1	F	0.0	0.69	3.73	0.13
		P	0.9882	0.4093	0.0574	0.7234

Table 6.19 Impact of Operating Conditions on Other Measures of Static Dampening Procedure

Effect	degree of Freedom	Statistic	Performance Measure: Finished Goods tardiness	Performance Measure: Number of Rescheduling Messages	Performance Measure: Number of Rescheduling Notices
LS	1	F	70.22	215.21	190.63
		P	0.0001	0.0001	0.0001
UL	1	F	13.26	0.01	0.09
		P	0.0005	0.9315	0.7601
CL	1	F	246.76	0.40	0.08
		P	0.0001	0.5300	0.7715
LSxUL	1	F	1.05	1.07	0.14
		P	0.3091	0.3053	0.7090
LSxCL	1	F	0.41	0.88	0.27
		P	0.5237	0.3517	0.6077
ULxCL	1	F	2.29	1.42	7.65
		P	0.1349	0.238	0.0072
LSxULxCL	1	F	0.49	0.38	1.69
		P	0.4876	0.5369	0.1980

significant. The second order interaction effect ($F = 0$, $p = 0.9882$) was not significant.

2. Finished Goods Tardiness

In terms of the finished goods tardiness, all the main effects were statistically significant while all the interaction effects were not significant (as seen in Table 6.19). Again, capacity utilization level imposed a strong impact on the performance of the static dampening procedure. The factors of uncertainty level and lot-sizing rule had strong influence as well.

3. Cost Components

The impact of operating conditions on the shortage cost followed a similar pattern to that on the finished goods tardiness, except that the main effect of uncertainty level ($F = 3.08$, $p = .0833$) was not significant. In terms of the inventory carrying cost, the main effects were all significant, but only the interaction effect between the lot-sizing rule and capacity utilization level ($F = 9.80$. $p < 0.0025$) was significant. When the set-up cost is considered, the main effects of lot-sizing rule ($F = 797.05$, $p < 0.0001$) and capacity utilization level ($F = 6.11$, $p < 0.0158$) were significnat. It is expected that EOQ and L4L would produce different set-up cost due to the frequency of open orders generated by these two lot-sizing rules. As discussed in the previous section, the uncertainty level did not affect the set-up cost associated with the use of the static dampening procedure significantly.

4. Rescheduling Statistics

In terms of the rescheduling messages generated by the static dampening procedure, the main effect of lot-sizing rule ($F = 215.21$, $p < 0.0001$) was the only significant one. Although different uncertainty levels may induce different number of rescheduling messages, the main effect of uncertainty level ($F = 0.01$, $p = 0.9315$) was not statistically significant when the static dampening procedure was used. Differing capacity utilization levels did not lead to significantly different numbers of rescheduling messages generated ($F = 0.40$, $p = 0.53$). Almost identical results can be concluded for the rescheduling notices, except that the interaction effect between the uncertainty level and capacity utilization level ($F = 7.65$, $p < 0.0072$) was significant. That is, when the factors of uncertainty level and capacity utilization level are combined it produced a significant impact on the number of rescheduling notices implemented by the static dampening procedure.

<u>Automatic Rescheduling Procedure</u>

1. Total Related Cost

All the main effects and first-order interaction effects were significant for the automatic rescheduling procedure (as shown in Table 6.20). The factor of capacity utilization level had a strong influence on the total related cost generated by the automatic rescheduling procedure as well as the factors of uncertainty level and lot-sizing rule. However, the strong interaction effects suggest that all the operating conditions must be examined together.

2. Finished Goods Tardiness

In terms of the finished goods tardiness, all the main effects were found to be significant in Table 6.21. It is noted that the factor of lot-sizing rule exerted an influence on the finished goods tardiness

Table 6.20 Impact of Operating Conditions on Cost-related Measures of Automatic Rescheduling Procedure

			Performance Measure			
Effect	degree of freedom	Statistic	Total Related Cost	Shortage Cost	Inventory Carrying Cost	Set-up cost
LS	1	F	31.11	52.41	232.31	370.85
		P	0.0001	0.0001	0.0001	0.0001
UL	1	F	15.82	4.69	36.18	9.03
		P	0.0002	0..336	0.0001	0.0036
CL	1	F	210.96	134.57	363.92	15.72
		P	0.0001	0.0001	0.0001	0.0002
LSxUL	1	F	10.37	1.52	48.73	15.75
		P	0.0019	0.2213	0.0001	0.0002
LSxCL	1	F	22.57	1.43	64.97	5.80
		P	0.0001	0.2362	0.0001	0.0186
ULxCL	1	F	23.64	1.78	17.91	35.92
		P	0.0001	0.1859	0.0001	0.0001
LSxULxCL	1	F	3.20	0.38	30.41	8.03
		P	0.0779	0.5379	0.0001	0.0060

Table 6.21 Impact of Operating Conditions on Other Measures of Automatic Rescheduling Procedure

			Performance Measure		
Effect	degree of Freedom	Statistic	Finished Goods tardiness	Number of Rescheduling Messages	Number of Rescheduling Notices
LS	1	F	156.88	91.96	91.96
		P	0.0001	0.0001	0.0001
UL	1	F	13.90	0.25	0.25
		P	0.0004	0.6199	0.6199
CL	1	F	239.46	38.23	38.23
		P	0.0001	0.0001	0.0001
LSxUL	1	F	4.05	0.50	0.50
		P	0.0478	0.4818	0.4818
LSxCL	1	F	7.45	20.14	20.14
		P	0.0080	0.0001	0.0001
ULxCL	1	F	2.48	0.23	0.23
		P	0.1198	0.6322	0.6322
LSxULxCL	1	F	1.45	1.89	1.89
		P	0.2331	0.1734	0.1734

generated by the automatic rescheduling procedure. This observation lends support to the explanation why the automatic rescheduling procedure performed rather well with L4L lot-sizing rule, but performed poorly with EOQ lot-sizing rule.

3. Cost Components

When the set-up cost and the inventory carrying cost were examined (see Table 6.20), all the main effects and interaction effects were statistically significant. In terms of the shortage cost, all the main effects were significant while all the interaction effects were not. This suggests that the main effects of operating conditions can be individually examined to investigate the performance of the automatic rescheduling procedure in terms of the shortage cost.

4. Rescheduling Statistics

Because the number of rescheduling messages was the same as that of rescheduling notices, the statistical analysis regarding rescheduling messages and rescheduling notices was identical. The main effects of the lot-sizing rule ($F = 91.96$, $p < 0.0001$) and capacity utilization level ($F = 38.23$, $p < 0.0001$) were significant as shown in Table 6.21. The main effect of uncertainty level ($F = 0.25$, $p = 0.6199$) was not significant probably because the number of rescheduling messages induced by different uncertainty level did not lead to significant difference in terms of rescheduling decisions made by the automatic rescheduling procedure. It is interesting to note that all the interaction effects were not statistically significant except the interaction effect between the lot-sizing rule and capacity utilization level ($F = 20.14$, $p < 0.0001$). This indicates that the combining effect of the lot-sizing rule and capacity utilization level would affect the degree of system nervousness generated by the automatic rescheduling procedure.

Cost-Based Dampening Procedure

1. Total Related Cost

The univariate F tests of the performance measures for the cost-based dampening procedure are presented in Tables 6.22 and 6.23. As indicated in Table 6.22, the main effects of capacity utilization level (F = 278.99, $p < 0.0001$) and uncertainty level (F = 12.44, $p < 0.0001$) were significant. The factor of capacity utilization level imposed an operational impact on the total related cost generated by the cost-based dampening procedure. The main effect of lot-sizing rule (F = 0.96, p = 0.3305) was not statistically significant. When associated with the use of EOQ, the cost-based dampening procedure performed very well due to the amplification effect of EOQ lot-sizing rule. Therefore, it closed the gap of the difference in the total related cost between the operating conditions that use EOQ and those that use L4L. As a result, the selection of lot-sizing rule did not significantly affect the total related cost generated by the cost-based dampening procedure. The interaction effects between lot-sizing rule and capacity utilization (F = 21.47, $p < 0.0001$), and the uncertainty level and capacity utilization level (F = 18.28, $p < .0001$) were significant, while that between lot-sizing rule and uncertainty level was not (F = 0.0, p = 0.9671). Also, the second order interaction effect (F = 0.33, p = 0.5693) was not significant in this dampening procedure.

2. Finished Goods Tardiness

Table 6.22 Impact of Operating Conditions on Cost-related Measures of Cost-based Dampening Procedure

			Performance Measure			
Effect	degree of freedom	Statistic	Total Related Cost	Shortage Cost	Inventory Carrying Cost	Set-up cost
LS	1	F	0.96	15.97	45.26	663.98
		P	0.3305	0.0002	0.0001	0.0001
UL	1	F	12.44	7.15	18.09	0.09
		P	0.0007	0.0093	0.0001	0.7647
CL	1	F	278.99	181.03	90.94	5.32
		P	0.0001	0.0001	0.0001	0.0239
LSxUL	1	F	0.0	1.90	0.15	2.48
		P	0.9671	0.1719	0.6963	0.1196
LSxCL	1	F	21.47	0.09	0.45	0.89
		P	0.0001	0.7657	0.5025	0.3480
ULxCL	1	F	18.28	0.23	4.31	178.30
		P	0.0001	0.6295	0.0414	0.0001
LSxULxCL	1	F	0.33	2.41	0.03	1.28
		P	0.5693	0.1252	0.8651	0.2611

Table 6.23 Impact of Operating Conditions on Other Measures of Cost-based Dampening Procedure

Effect	degree of Freedom	Statistic	Performance Measure: Finished Goods tardiness	Performance Measure: Number of Rescheduling Messages	Performance Measure: Number of Rescheduling Notices
LS	1	F	72.87	258.40	270.14
		P	0.0001	0.0001	0.0001
UL	1	F	31.87	2.78	4.0
		P	0.0001	0.0996	0.0493
CL	1	F	254.10	0.16	0.06
		P	0.0001	0.6896	0.8071
LSxUL	1	F	3.42	1.49	1.65
		P	0.0684	0.2262	0.2035
LSxCL	1	F	1.42	0.04	0.38
		P	0.2371	0.8374	0.542
ULxCL	1	F	0.82	6.52	6.88
		P	0.3678	0.0128	0.0106
LSxULxCL	1	F	2.25	1.42	0.99
		P	0.1381	0.2371	0.3228

All the main effects and interaction effects were significant while all the interaction effects were not significant as shown in Table 6.23. That is, when analyzing the finished goods tardiness for the cost-based dampening procedure, each mean response can be obtained by adding the main effects tc the overall mean. It should be noted that the lot-sizing rule imposed an effect on the finished goods tardiness for the cost-based dampening procedure. L4L lot-sizing rule is more responsive to the MPS changes than EOQ. Thus, L4L would certainly produce a better performance in terms of the finished goods tardiness than EOQ.

3. Cost Components

The statistical analysis of the shortage cost followed a similar pattern to that of the finished goods tardiness. As seen in Table 6.22, it is interesting to note that only the main effects were significant while all the interaction effects were not significant except the interaction effect between uncertainty level and capacity utilization level ($F = 4.31$, $p < 0.0414$), in terms of inventory carrying cost. In terms of the set-up cost, the main effects of lot-sizing rule ($F = 663.98$, $p < 0.0001$), and capacity utilization level ($F = 5.32$, $p < 0.0239$), and the interaction effect between uncertainty level and capacity utilization level ($F = 178.3$, $p < 0.0001$) were significant. This continues the mixed impact of dampening procedure selected on the set-up cost just like the first two dampening procedures discussed.

4. Rescheduling Statistics

As seen in Table 6.23, the only significant effects are the main effect of lot-sizing rule ($F = 258.4$, $p < 0.0001$) and the interaction effect between uncertainty level and capacity utilization level (F =

6.52, $p < 0.0128$) in terms of rescheduling messages generated by the cost-based dampening procedure. This is a very important feature of the cost-based dampening procedure. This suggests that the use of lot-sizing rule affect the number of rescheduling messages generated if the cost-based dampening procedure is used. The number of open orders determined by EOQ and L4L still made a significant difference in the number of rescheduling messages generated. Because the cost-based dampening procedure effectively screened out the "insignificant" rescheduling messages, the numerical difference of rescheduling messages induced by the different uncertainty level ($F = 2.78$, $p = 0.0996$) and different capacity utilization level ($F = 0.16$, $p = 0.6896$) were not significant for the cost-based dampening procedure.

An almost identical result was reached for the number of rescheduling notices implemented by the cost-based dampening procedure, except that the main effect of uncertainty level ($F = 4.0$, $p < 0.0493$) was significant. It appears that if using the cost-based dampening procedure, the entire system would not be more nervous when the higher capacity level is utilized.

The major findings in this section are presented as follows.

1. The capacity utilization level exerted an influence on many performance measures for each dampening procedure. Because the high capacity utilization level imposed a severe operating environment for this simulated factory, it generally led to the poor performance for each dampening procedure. However, different capacity utilization level did not lead to significant difference in rescheduling statistic for the static dampening procedure and the cost-based dampening procedure.

2. The factor of uncertainty level affects all the dampening procedures in terms of most of performance measures, except for rescheduling statistics. This is probably because the number of rescheduling messages induced by different uncertainty level was not signifcantly different for all the dampening procedures.

3. The factor of lot-sizing rule imposed significant impact on the cost components for the dampening procedures tested. The lot-sizing rule was a very influential experimental factor in terms of rescheduling messages and rescheduling notices. This is simply because a significantly different number of open orders released by EOQ and L4L which, in turn, is the source of rescheduling messages and rescheduling notices.

4. The set-up cost did not seem to be affected by the use of dampening procedure in any systematic pattern. This suggests that no matter what dampening procedure was used, the set-up cost was not affected significantly.

5. If the cost-based and static dampening procedures were used, MRP system would not be any more nervous under the high uncertainty level or high capacity utilization level than under the low uncertainty level or low capacity utilization level respectively. It leads to a very important conclusion that the cost-based and static dampening procedures can effectively reduce MRP system nervousness under the two environmental factors studied in this research.

Thus far, the discussion of the impact of operating conditions on the relative performance upon the dampening procedures has focused on the results of hypothesis testing on the main effects and interaction effects of all the experimental factors. Some interesting insights were drawn from the discussion. In the next section, other hypotheses stated in Chapter Five will be tested and insights will be drawn from the hypothesis testing.

Related Hypothesis Testing

Hypothesis 2, as stated in Chapter Five, is that the performance of the dampening procedures tested tends to converge under the low capacity utilization level while the more comprehensive dampening procedure tends to perform well under the high utilization capacity level. In order to test this hypothesis, a one way ANOVA is performed, in which dampening procedure is the independent variable, for each capacity utilization level in terms of the total related cost and finished goods tardiness. The results are presented in Table 6.24.

It was found that the performance, measured by the total related cost or finished goods tardiness, of the dampening procedures tested indeed converged at the low capacity utilization level. Under the high capacity utilization level, the cost-based dampening procedure performed significantly better than the automatic rescheduling procedure in terms of the total related cost or finished goods tardiness. However, the difference in these two performance measures between the static dampening procedure and cost-based dampening procedure, and that between the static dampening procedure and automatic rescheduling procedure were not significant.

The results of this hypothesis testing provides some interesting implications. At the low capacity utilization level, a production system has sufficient slack to absorb schedule changes resulting from the occurrence of uncertain events. The selection of a dampening procedure has very little impact on the system performance. As the capacity utilization rate increasd, the system slack declines. The cost-based dampening procedure performed very well under the high capacity utilization level because this dampening procedure does not depend upon the system slack to deal with rescheduling problems. Therefore, it becomes more important in selecting an appropriate dampening procedure in the operating conditions associated with the high capacity utilization level.

Table 6.24 Results of Testing Hypothesis Two

		Total Related Cost			Finished Goods Tardiness		
		D1	D2	D3	D1	D2	D3
Low Cap	Ranking	2	3	1	2	3	1
	Mean	13.623	13.656	13.591	2.9419	3.3111	2.940
	D1 vs D2		N			N	
	D1 vs D3		N			N	
	D2 vs D3		N			N	
	Least Sig Diff		0.1031			0.5702	
High Cap	Ranking	2	3	1	2	3	1
	Mean	14.343	14.46	14.291	5.3657	5.6703	5.2726
	D1 vs D2		N			N	
	D1 vs D3		N			N	
	D2 vs D3		Y			Y	
	Least Sig Diff		0.1637			0.3689	

Decision Rules for Selecting Dampening Procedures

In this section, dampening procedures are compared according to the performance measures in the operating conditions under study. The initial results obtained from the analysis of variance indicate significant interaction effects still exist after the logarithmic transformation is performed on the performance measures. Therefore, the dampening procedures were compared in each possible operating condition, characterized by different combinations of experimental factors, for a more comprehensive analysis. Then, decision rules are proposed to provide guidelines for better management of MRP system nervousness.

There are two types of decision criteria that should be addressed. The first type of decision criteria are the secondary performance measures collected in this study, such as the shortage cost or inventory carrying cost. Some companies may emphasize the improvement in customer service level while other companies may be interested in the reduction of inventory carrying cost. The decision criteria of secondary measures will be fully explored in this section.

The second type of decision criteria involves the cost or effort in the development of a dampening procedure to be implemented. In the case of the static dampening procedure, material planners need to determine an appropriate "no rescheduling fence" which is suitable for their operating enrironments. As discussed previously, a "no rescheduling fence" is actually reflected by the system flexibility of a given operating condition. In no way is it an easy task to find an optimal rescheduling fence.

As for the automatic rescheduling procedure, the minimum lead time of an open order during various stages of fabrication must be maintained in the job ticket. If the minimum lead time can be defined properly, this dampening procedure is easy to implement.

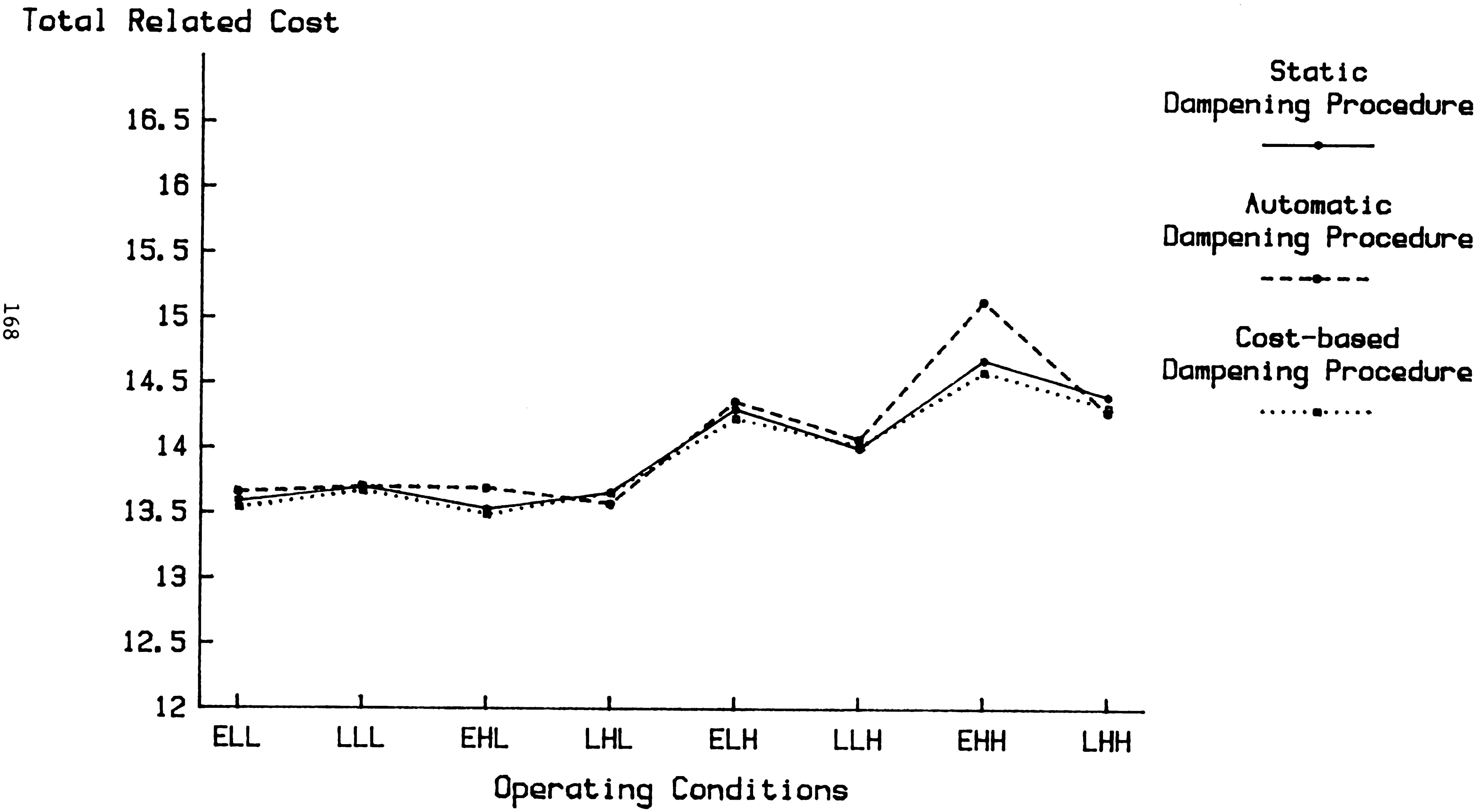
In the development of the cost-based dampening procedure, it is necessary to keep track of cost information in the job order in order to calculate the cost of rescheduling and the cost of not rescheduling when an open order needs to be rescheduled. Also, the jobs waiting in front of the open order that need to be rescheduled must be determined. With the advanced manufacturing information systems currently available, the difficulty in keeping track of these information may be reduced.

The following discussion is based on the performance of dampening procedures for the total related cost, finished goods tardiness, cost components and rescheduling statistics, respectively.

Total Related Cost

In Figure 6.3, the total related cost generated by the three dampening procedures are plotted against the eight operating conditions under study. As seen in Figure 6.3, the total related cost generated by the dapmening procedures did not have significant difference, except for EHH. Although the cost-based dampening procedure performed rather well and the automatic rescheduling procedure performed poorly in most of the operating conditions tested, the selection of a dampening procedure to cope with MRP system nervousness may depend upon some other decision criteria.

Figure 6.3 Comparison of Dampening Procedures by Total Related Cost



In those operating conditions that were associated with the low capacity utilization level, a parallel difference between the static dampening procedure and cost-based dampeing procedure was observed. In the operating conditions which were associated with the high capacity utilization level, the automatic rescheduling procedure performed poorly, particularly in EHH. As investigated previously, in EHH, due to the interaction among EOQ lot-sizing rule, high capacity utilization level and high uncertainty level, the performance of all the dampening procedures deteriorated considerably. The main reason for this phenomenon was that the actual lead time of finished goods increased dramatically. As a result, the finished goods tardiness and shortage cost increased accordingly. Furthermore, the inventory carrying cost generated by the automatic rescheduling procedure increased significantly relative to that by the other dampening procedures.

The environmental factors studied, capacity utilization level and uncertainty level, did affect the performance of each dampening procedure as discussed in the previous section. It appears that these environmental factors did not have significant impact on the selection of dampening procedure to cope with MRP system nervousness (see Figure 6.3). This implies that the selection of lot-sizing rule may have more impact on the selection of dampening procedure than the existence of environmental factors. Nevertheless, under the high capacity utilization level, it is necessary to adopt other uncertainty buffering techniques, such as safety stock, in order to deal with the uncertain events effectively.

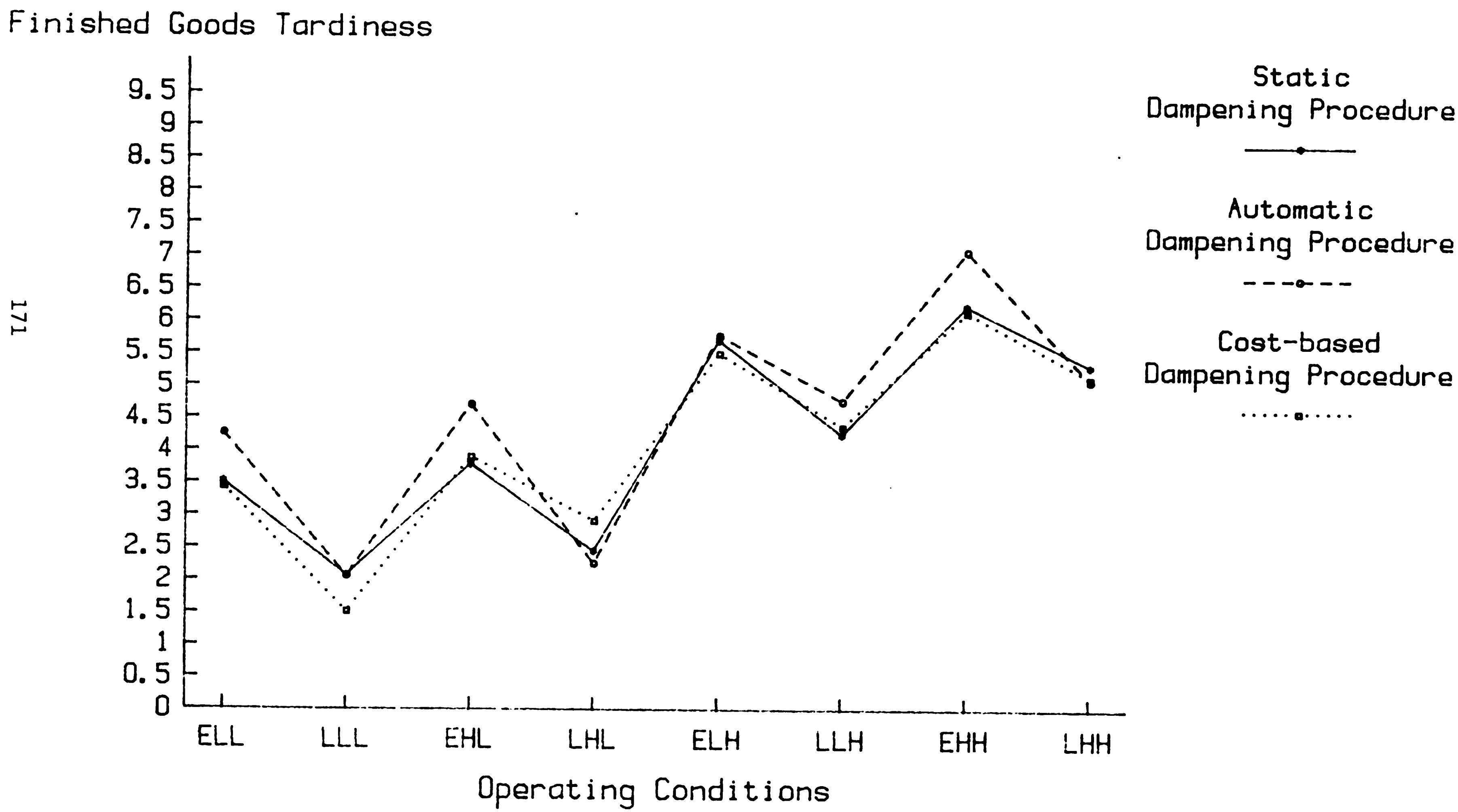
The major decision guidelines stemming from the total related cost ananlysis is that the performance of the cost-based dampening procedure was not significantly distinguished from the other dampening procedures, and other decision criteria may become the determining factors to select a dampening procedure to cope with MRP system nervousness. In general, the cost-based dampening procedure performed very well with the use of EOQ lot-sizing rule. The static dampening procedure is a viable alternative to the cost-based dampening procedure, if there is any difficulty in implementing the cost-based dampening procedure in a certain operating condition. However, an appropriate "no rescheduling fence" needs to be determined in order for the static dampening procedure to function adequately.

If other selection criteria are used to determine the dampening procedure because of statistical insignificance, the cost-based dampening procedure does take more effort for material planners to develop than the automatic rescheduling procedure or static dampening procedure. However, as long as the cost information is maintained in the job order, the difficulty of implementing the cost-based dampening procedure can be reduced. From the viewpoint of this type of selection criteria, the cost-based dampening procedure does not suffer serious disadvantage.

Finished Goods Tardiness

Since the finished goods tardiness can serve as a surrogate measure of customer service level, the decision rules suggested here can be generalized for companies mainly concerned with their customer service level. Figure 6.4 indicates that the performance measure generated by the static and cost-based dampening procedure did not have significant difference in all the operating conditions. The following guidelines are proposed based on the results of the finished goods tardiness

Figure 6.4 Comparison of Dampening Procedures by Finished Goods Tardiness



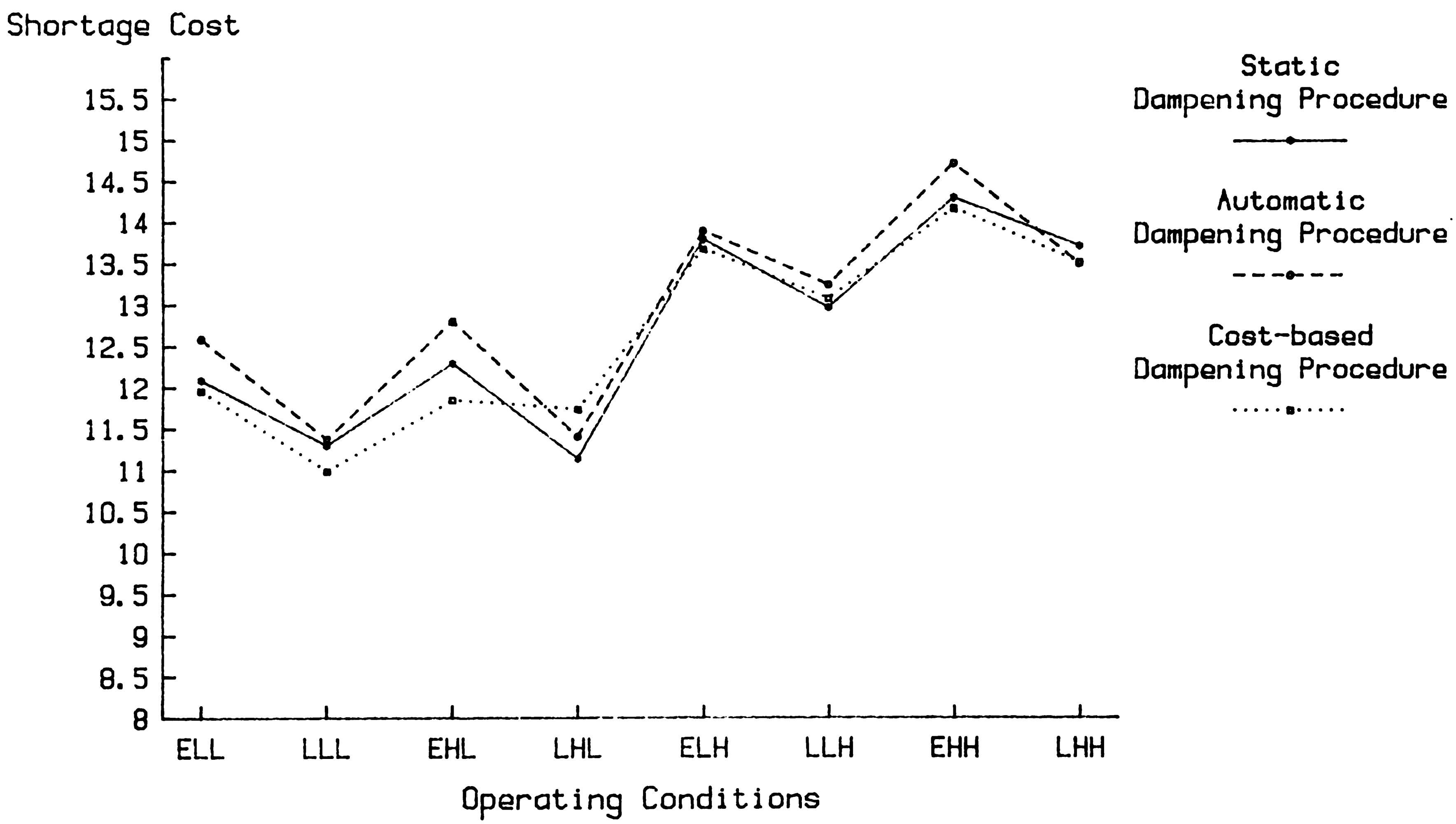
analysis.

In ELL, EHL, LLH, and EHH, the static and cost-based dampening procedures were the better dampening procedures than the automatic rescheduling procedure. Thus, one should be cautious in using the automatic rescheduling procedure along with EOQ lot-sizing rule which generally resulted in very poor performance. In other operating conditions, the selection of dampening procedure may depend upon some other decision criteria as discussed earlier. It is recommended that the cost-based dampening procedure be used if the difficulty in collecting the cost information can be resolved.

Cost Components

From Figure 6.5, the shortage cost generated by the dampening procedures was not significantly different when L4L lot-sizing rule was used. This is because L4L lot-sizing rule, by itself, is very responsive to any schedule change. In those operating conditions that are associated with the use of EOQ lot-sizing rule, the cost-based dampening procedure consistently outperformed the automatic rescheduling procedure. Therefore, when there are more open orders to be rescheduled potentially, induced by the use of L4L lot-sizing rule, the rescheduling decision determined by a certain dampening procedure becomes less important. On the other hand, fewer open orders generated by EOQ lot-sizing rule tends to make a dampening procedure for rescheduling decisions more important. Still, without further investigation, it cannot be concluded that the performance of dampening procedures tested would make significant difference when a lot-sizing rule that would generate fewer open orders than L4L, such as part period balancing, is used.

Figure 6.5 Comparison of Dampening Procedures by Shortage Cost

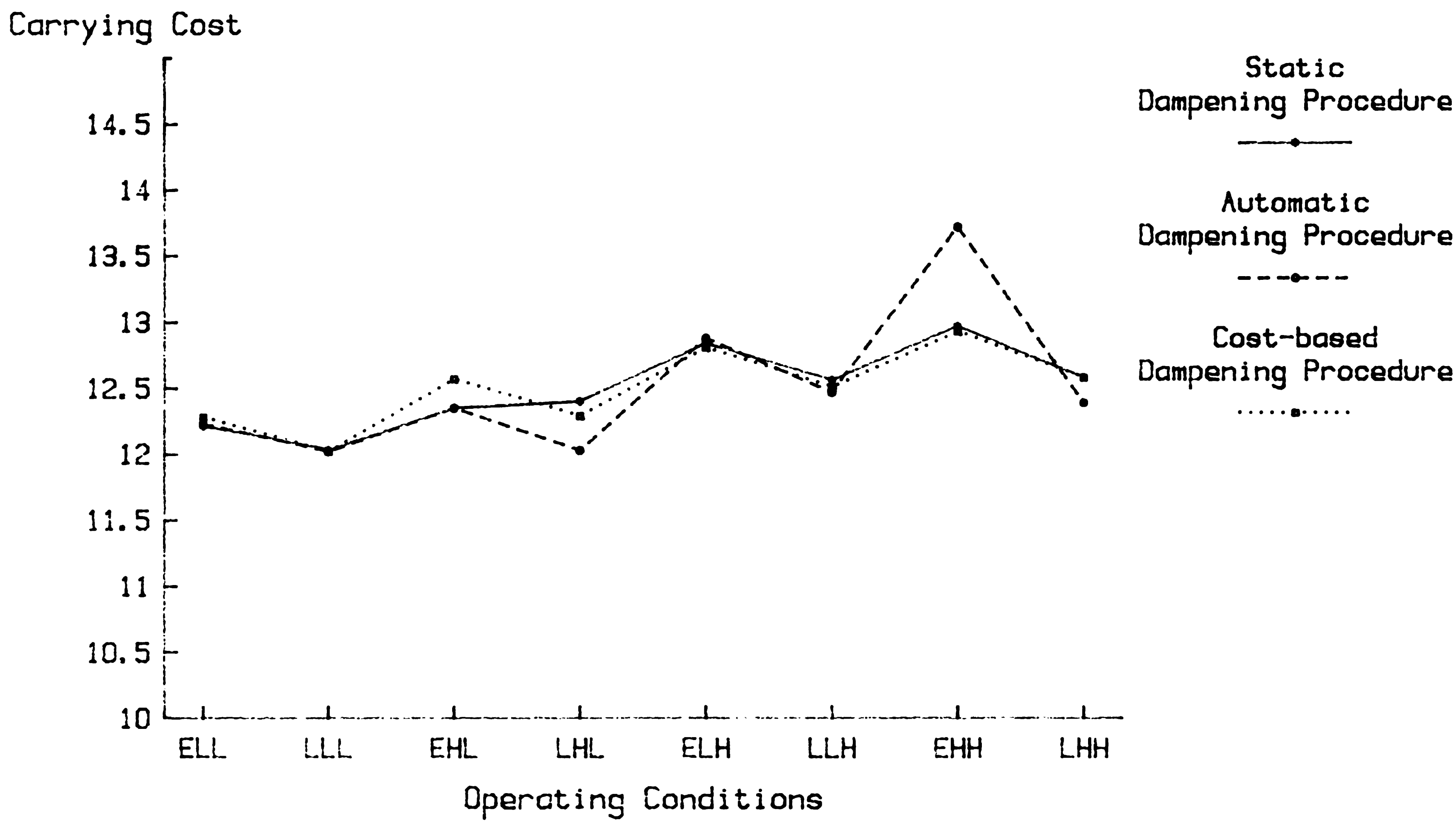


Based on the simulation results, it is recommended that the cost-based and static dampening procedures be used if EOQ lot-sizing rule is used, especially in EHH. In those operating conditions where L4L lot-sizing rule was used, the performances of these dampening procedures were not significantly different from each other. Therefore, other decision criteria mentioned earlier plays an important role in selecting a dampening procedure to cope with MRP system nervousness. Once again, environmental factors, especially uncertainty level, have very little impact on the selection of a dampening procedure in terms of the shortage cost.

It is interesting to note from Figure 6.6 that there are four operating conditions in which these three dampening procedures did not perform differently in terms of the inventory carrying cost. It also indicates that the automatic rescheduling procedure performed rather well in most operating conditions due to its responsiveness to schedule changes, except in EHH. On the contrary, the cost-based dampening procedure did not perform well, when measured by the inventory carrying cost.

It is suggested that for companies which are concerned about the inventory carrying cost, the automatic rescheduling procedure was a good dampening procedure for some operating conditions under study. However, the higher responsiveness of cost-based dampening procedure to schedule changes, compared with the static dampening procedure, did not lead to improvement over the static dampening procedure in terms of the inventory carrying cost. Thus, it does not make any difference whether material planners choose the static or cost-based dampening procedures.

Figure 6.6 Comparison of Dampening Procedures by Carrying Cost



In Figure 6.7, the set-up cost generated by the dampening procedures is plotted against the operating conditions studied. This figure best illustrates the fact that the selection of a dampening procedure has very little impact on the set-up cost. The only operating condition that makes a significant difference is that of EHH. Under this operating condition, the automatic rescheduling procedure behaved very erratically. A lot of open orders spent time waiting for the component parts in shortage which increased the inventory carrying cost. At the same time, the automatic rescheduling procedure reduced the number of set ups because fewer open orders seized the machines to be processed. Therefore, material planners do not need to consider the set-up cost when selecting a dampening procedure to be implemented.

<u>Rescheduling Statistics</u>

Figure 6.8 shows that the cost-based dampening procedure consistently generated the fewest rescheduling messages in all the operating conditions. Under the low capacity utilization level, the automatic rescheduling procedure and cost-based dampening procedure generated approximately the same number of rescheduling messages. Due to the "no rescheduling fence" established in this research, the static dampening procedure continously regenerated the screened out rescheduling messages over the life of an open order. Thus, the static dampening procedure created more rescheduling messages than did the cost-based dampening procedure in most of the operating conditions. The lot-sizing rule used did affect the number of rescheduling messages generated by the dampening procedures, but did not affect the selection between the static and cost-based dampening procedures to be implemented in terms of the number of rescheduling messages.

Figure 6.7 Comparison of Dampening Procedures by Set-up Cost

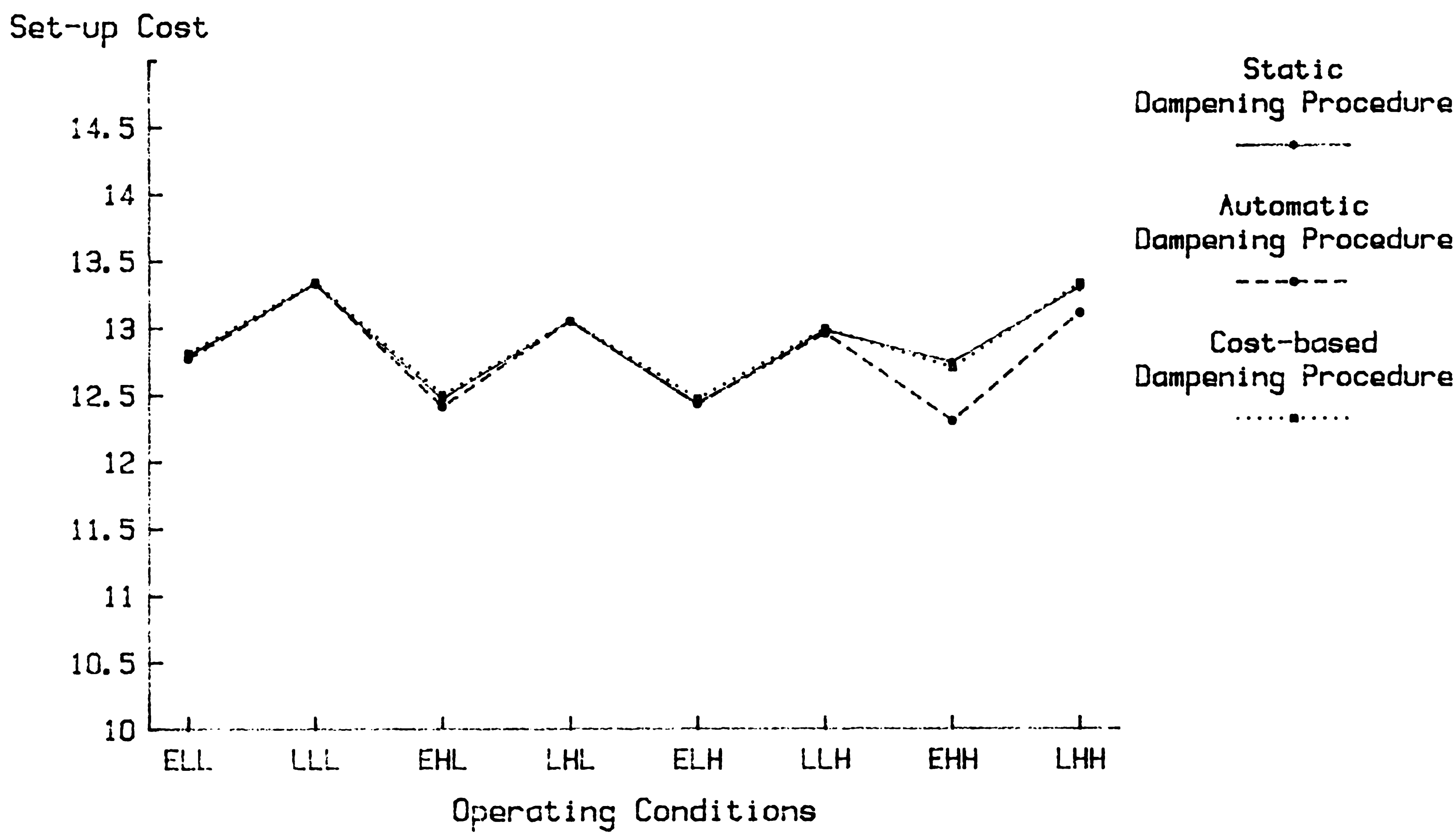
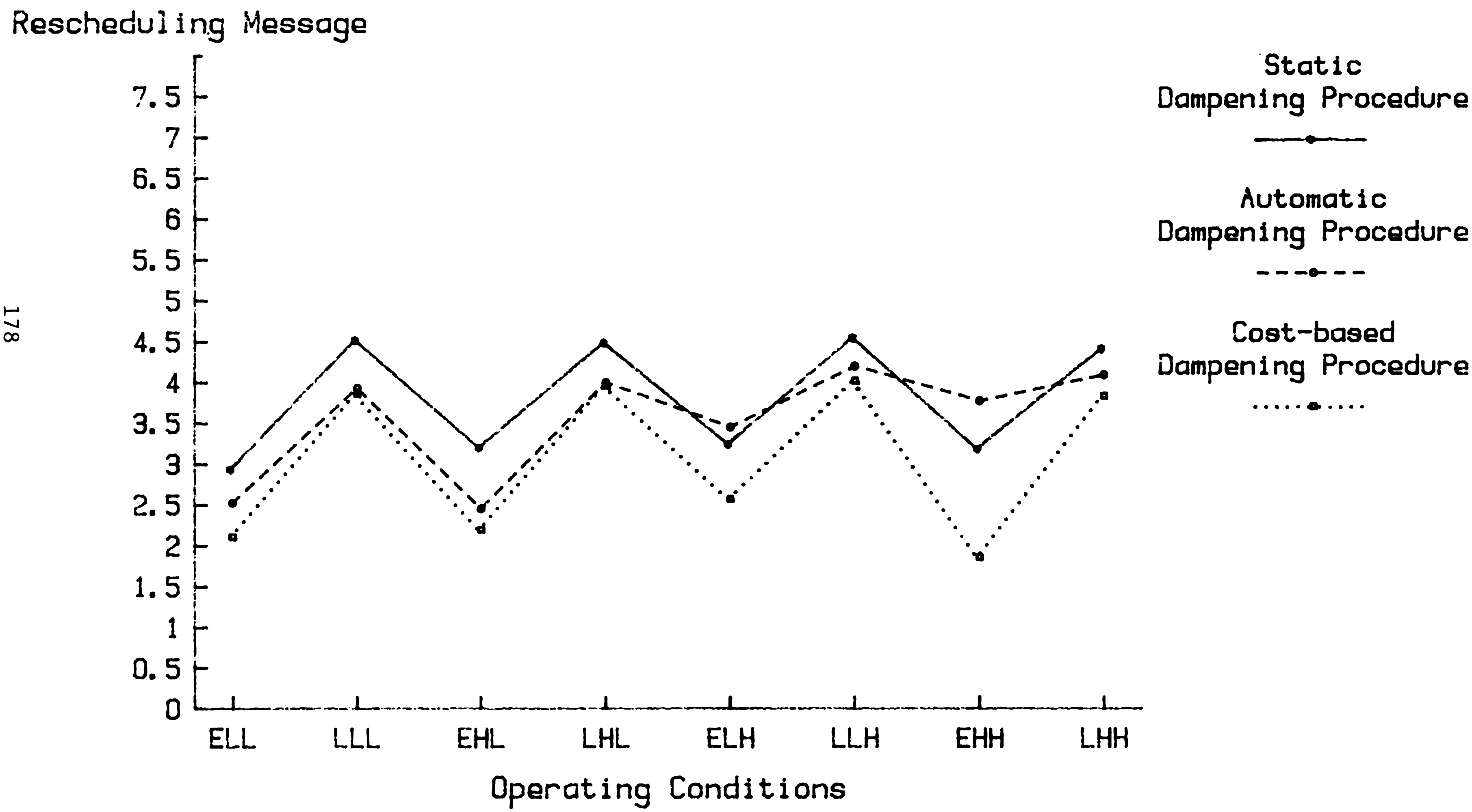


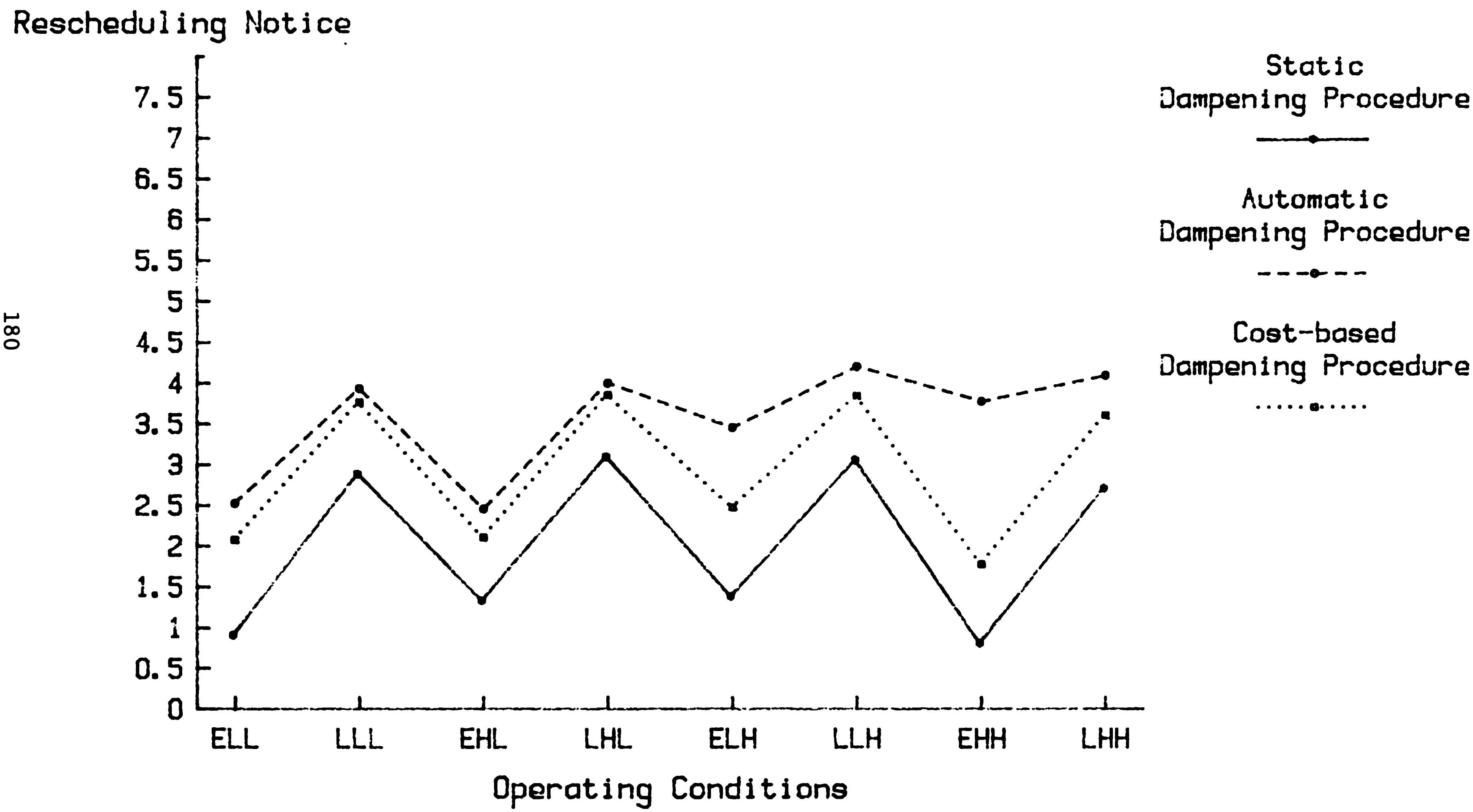
Figure 6.8 Comparison of Dampening Procedures by Rescheduling Message



The number of rescheduling messages should not be used as a sole decision criterion to select a dampening procedure, because this performance measure reflects the uncertainty level encountered and the difference in the decision-making mechanism of the dampening procedures tested. However, it can be used as a supplementary decision criterion, when the performances of dampening procedures are not significantly different measured by some major performace measure, such as the total related cost or finished goods tardiness. The more rescheduling messages generated, the more time and effort material planners take to analyze the rescheduling messages. Thus, the cost-based dampening procedure outperformed the other dampening procedures in ths aspect.

When the number of rescheduling notices is plotted against the operating conditions (Figure 6.9), the static dampening procedure, as expected, generated the fewest rescheduling notices. The performance of automatic rescheduling procedure and cost-based dampening procedure, measured by the number of rescheduling notices, was not significantly different in the operating conditions characterized by the low capacity utilization level. Nevertheless, the cost-based dampening procedure consistently generated fewer rescheduling notices than the automatic rescheduling procedure. The fewer rescheduling notices implemented, the less nervous the production system is. However, as emphasized previously, the less nervous system does not lead to better system performance as measured by the total related cost or other secondary performance measures. Therefore, just like the number of rescheduling messages, the number of rescheduling notices should not serve as a sole decision criterion unless it is extremely expensive to change order priority on the shop floor.

Figure 6.8 Comparison of Dampening Procedures by Rescheduling Notice



Generally speaking, the static dampening procedure indeed generated the fewest rescheduling notices and created a less nervous working environment. As a guideline for rescheduling statistics, it is suggested that material planners select the static dampening procedure if other performance measures are not significantly different. Furthermore, in a situation of indifference between the automatic rescheduling procedure and cost-based dampening procedure, the cost-based dampening procedure is the better dampening procedure in terms of the number of rescheduling notices implemented.

Summary of Chapter Six

The data analysis and experimental results have been summarized in this chapter. The major findings emerging from the experimental results, along with implications to academicians and practitioners, will be presented in the next chapter. Once again, it should be noted that the results and conclusions presented above apply to the dampening procedures tested in the operating conditions under study.

CHAPTER SEVEN

SUMMARY AND CONCLUSION

The objective of this research has been to measure MRP system nervousness operationally; and to investigate the alternative global dampening procedures to cope with MRP system nervousness. A large-scale simulation study was undertaken in order to achieve this objective. This chapter presents the research findings resulting from this simulation experiment. This research should contribute to the understanding of MRP system nervousness and dampening procedures for both practitioners and academicians.

This chapter begins with a summary of the major findings. Then, the contributions of this study, to both practitioners and academicians, are discussed. Finally, this chapter concludes with some suggestions for future research.

Summary of the Major Findings

This study addresses two major research issues: (1) the effectiveness of alternative dampening procedures; and (2) the impact of various operating conditions on the performance of these dampening procedures. Based on the simulation results analyzed in Chapter Six, the following conclusions were reached:

1. The results of this study indicate that there still have significnat interaction effects among the experimental factors after the logarithmic transformation is performed. This suggests that these factors should be examined together, rather than independently, to make sure that the best dampening procedure is used to cope with MRP system nervousness in a multiproduct and multistage simulated factory. Due to these strong interaction effects, some interaction among factors produce dramatic results, such as EHH. The assembly lead time lengthens considerably which deteriorates the performance of all the dampening procedures, especially the automatic rescheduling procedure.

2. The relative performance, measured by the total related cost, of alternative dampening procedures is not significantly different in most of the operating conditions under study. This seemingly suggests that material planners choose any dampening procedure that is suitable for their operating environment. This result not only supports Penlesky's (1982) major conclusion that the heuristic dampening procedures do not perform differently, it also broadens his single experimental condition to the eight operating conditions tested in this study. Consequently, other decision criteria, rather than the total related cost, play an important role in selecting an appropriate dampening procedure. The decision criteria may be some secondary performance measure or the effort or cost of developing a dampening procedure to be implemented.

The dampening procedure proposed in this study, the cost-based dampening procedure, is not difficult to implement compared with the other dampening procedures. However, a firm needs to invest in the required software or hardware, if not available, to establish a manufacturing information system to gather the necessary information.

3. When other performance measures are considered, such as the finished goods tardiness, the performance of cost-based dampening procedure improves in those operating conditions that are associated with the use of EOQ lot-sizing rule. Generally speaking, the automatic rescheduling procedure is a relatively poor dampening procedure in most of the operating conditions. However, with the interaction between high uncertainty level and L4L lot-sizing rule, the automatic rescheduling procedure performs rather well. Therefore, the selection of lot-sizing rule affects that of dampening procedure considerably.

4. When investigating the impact of operating condition on the performance of dampening procedure, it was found that capacity utilization level imposed some influence on many performance measures collected in this study. The implication of this influence is that when a scheduling problem results from insufficient capacity, dampening procedures are not effective in resolving this type of scheduling problem. The factors of uncertainty level and lot-sizing rule affect the performance of dampening procedure very little under the low capacity utilization level. In the operating conditions associated with high capaicty utilization level, the impact of selecting an appropriate dampening procedure on the system performance becomes stronger.

5. MRP system nervousness is not necessarily related to the total related cost, or other performance measures. From a hypothesis testing regarding the relationship among the nature of lot-sizing rule, MRP system nervousness, and total related cost, it was found that the dynamic lot-sizing rule indeed caused a higher degree of system nervousness, reflected by the larger number of rescheduling notices, but it also produced better overall system performance, measured by the

total related cost or finished goods tardiness. These results support the claim that MRP system nervousness is not necessarily an evil, but reflect the responsiveness of a production system to schedule changes.

6. When the cost components of total related cost are examined in detail, some interesting results emerge. First, the shortage cost behaves very similarily to finished goods tardiness. The calculation of shortage cost is based on the length of finished goods delayed. Based on this secondary performance measure, the static and cost-based dampening procedures outperform the automatic rescheduling procedure significantly in some operating conditions, while the automatic rescheduling procedure performs well in the operating conditions which are characterized by higher uncertainty level and L4L lot-sizing rule. Secondly, the responsiveness of automatic rescheduling procedure leads to better performance in terms of the inventory carrying cost in most operating conditions. The cost-based dampening procedure does not perform well, and is not distinguished from the static dampening procedure. Finally, the use of any dampening procedure does not affect the set-up cost. It implies that the set-up cost becomes relatively constant when comparing the performance of dampening procedure.

7. The selection of a dampening procedure significantly affects the number of rescheduling messages generated, and the number of rescheduling notices implemented. Reducing MRP system nervousness, reflected by the number of rescheduling notices implemented, would not necessarily lead to better system performance. Nevertheless, the number of rescheduling messages and rescheduling notices are suggested to serve as the supplementary decision criteria, rather than the sole decision criteria.

8. At the low capacity utilization level, a production system has sufficient slack to accommodate schedule changes. The performance of the dampening procedures tested tended to converge under this condition. However, the cost-based dampening procedure performed significantly better than the automatic rescheduling procedure under the high capacity level. This is mainly because the cost-based dampening procedure is independent of the system slack to deal with rescheduling problems.

Contributions of This Study to Practitioners and Academicians

The findings reported in this study have important implications for both practitioners and academicians. The major contribution of this study to practitioners is the proposed guideline regarding the selection of an appropriate dampening procedure to cope with MRP system nervousness. This guideline is mainly derived from the investigation of the impact of operating conditions on the relative performance of global dampening procedures. To academicians, this study first illustrates that the rescheduling capability of MRP systems is an alternative for dealing with production uncertainty. This study then points out two major misperceptions in studying MRP system nervousness. Also, the relationship between system nervousness and the nature of lot-sizing rule has been an interesting issue for academicians, which practitioners downplay the significance of using dynamic lot-sizing rules.

Contributions of This Study to Academicians

1. View Rescheduling as an Uncertainty Buffering Technique

Conventionally, safety stock, safety lead time, and safety capacity are the methods used to deal with production uncertainty. With the advent of MRP systems, rescheduling capability can handle production uncertainty, to a certain extent, by manipulating manufacturing information. The use of safety stock or safety lead time usually leads to extra inventory. Since inventory has been touted as "graveyard" of American firms, safety stock is losing its popularity as a method for counteracting production uncertainty. Safety lead time and safety capacity are rarely used in the real system (Whybark & Williams, 1976).

The rescheduling capability of MRP systems can resolve the uncertainty problem in some operating conditions without carrying additional inventory. How the rescheduling capability resolves unplanned events has been illustrated in Chapter 1. It should be noted that an MRP system alone is simply a manufacturing information system. Without the rescheduling capability, an MRP system cannot resolve an unplanned event. Therefore, it is important to point out the significance of the use of rescheduling capability with the MRP systems for dealing with production uncertainty. Based on the experimental results, it should be recognized that this rescheduling capability may run into problems in high capacity utilization level. Under the low capacity utilization level, a production system has sufficient slack to absorb uncertain events, through the generation of rescheduing messages, to realign the priority properly. When this system slack disapears in the high capacity utilization level, rescheduling capability, by itself, is not sufficient to deal with uncertain events.

2. Focus on Open Order Rescheduling in Timimg

Carlson et al. (1979) and Peterson (1975) suggested that open orders may be altered in quantity. Open order rescheduling in quantity seems to be a viable alternative, but some implementation problems are involved. As discussed previously, when an uncertain event cannot be revolved by rescheduling open orders in timing, one can always resort to less-than-lead-time planned order releases. Therefore, open order rescheduling in timing should be sufficient to deal with unexpected events, if the rescheduling capability of MRP systems is used to deal with production uncertainty. In view of the problems associated with open order rescheduling in quantity, it may not be worthwhile to consider it as an alternative.

3. Focus on Open Order Rescheduling, Not Planned Order

Most of the recent research in MRP system nervousness were focused on system nervousness resulting from planned order (Blackburn et al., 1983; Carlson et al., 1979; Kropp et al., 1979). It should be noted that system nervousness, or scheduling instability, mainly results from rescheduling open orders so frequently that a production system fails to respond. When an open order is rescheduled, the priority planning system must be adjusted in order to implement the rescheduling notice. On the other hand, the changes in planned order may create a problem of coverage for the low level items, but it is likely to be resolved by rescheduling an existing open order when passing down to the low level items. At worst, the timing of releasing low level items needs to be offset by shorter than normal lead time. Subsequently, expediting is required to solve this problem.

The impact of planned order diminishes as its position in the planning horizon moves toward the cumulative lead time. That is, changes in planned order releases have a gradually declining impact on its low level items. If the change occurs beyond the cumulative lead time, there is no schedule change of the lower-level items. On the other hand, the impact of open orders on the production system should be consistently greater than that of planned orders. It is mainly because any change in due dates of open orders would interrupt the priority planning of that open order provided that a due-date oriented dispatching rule is used. Therefore, the future focus of studying system nervousness should place emphasis on open order rescheduling, not planned order rescheduling.

4. The Relationship Between Lot-sizing Rules and System Nervousness

There has been a long-lasting disagreement between practitioners and academicians in the use of dynamic lot-sizing rules. Academicians claim that dynamic lot-sizing rules provide better results over some simple lot-sizing rules, such as EOQ (Berry, 1972; Biggs et al., 1977; Silver and Meal, 1973). However, these sophisticated lot-sizing rules, such as Wagner-Whitin or Silver-Meal algorithms, are rarely used in the real system (Mather, 1984). One of the major reasons is that dynamic lot-sizing rules tend to create higher degree of system nervousness (Mather, 1977).

In this study, two sets of hypotheses have been tested to examine this dispute. A dynamic lot-sizing rule, L4L in this study, indeed generated a higher degree of system nervousness than a static lot-sizing rule, EOQ. However, in terms of total related cost, the dynamic lot-sizing rule outperformed the static lot-sizing rule in most operating conditions. It should be remembered that system nervousness is merely a symptom that reflects the degree of uncertainty existing in the production system, and difference in decision-making mechanisms adopted in each dampening procedure. Total related cost is the overall measurement of system performance. Therefore, this research indeed confirms researchers' findings about the advantages of using dynamic lot-sizing rules from the perspective of overall system performance.

Contributions of this Study to Practitioners

1. Establishment of Classification Framework for Studying the Relative Performance of Local Dampening Procedures

A research framework has been established to classify dampening procedures into "local" and "global" ones. In this study, a common misperception of firm planned order as a method to deal with uncertainty has been pointed out. A firm planned order is simply a system command to prevent an order from being revised in the next MRP replanning. This technique must be accompanied by some local dampening procedure in order to resolve uncertain events.

The local dampening procedures in the literature have been identified mostly by practitioners. However, each local dampening procedure was presented individually. This thesis provides a framework to classify them in terms of the nature (timing or quantity) of production uncertainty, and the level in the product structure. Each local dampening procedure has its own merits and shortfalls. Before a local dampening procedure is implemented, planners should evaluate their own production environment to see if a local dampening procedure fits in their situation. Probably, planners first need to consider whether they are better off to use a global dampening procedure instead of local one, because global dampening procedures deal with a broader scope of uncertain events than local dampening procedures. This classification framework can serve as a guideline for planners to select an appropriate local dampening procedure to deal with the specific type of uncertainty they are experiencing.

2. Development of a Cost-based Global Dampening Procedure

Since the static dampening procedure and the automatic rescheduling procedure tend to ignore some significant manufacturing information, this motivated the development of a cost-based dampening procedure in this study. The cost-based dampening procedure incoporates some job-related information, such as operation due date, to make rescheduling decision.

Figure 7.1 provides a summary of the major characteristics of these three dampening procedures, which can provide insights for planners to choose an appropriate global dampening procedure. It is noted that "no dampening procedure" and "no rescheduling procedure" are added to serve as the bench marks for comparison. This figure is self-explanatory, but it requires further elaboration of dimensions used. The dimension of system interruption simply means a change of due dates in priority planning as a result of implementing rescheduling notices. This dimension actually can be viewed as a correlate of system nervousness. Modeling complexibility is the amount of information incorporated in the design of dampening procedure. Developmental cost is the expected cost required to develop and implement a dampening procedure. Cost consideration or capacity consideration is the specific job-related information involved in the design of a global dampening procedure.

	No Dampening Procedure	Static Dampening Procedure	Automatic Rescheduling Procedure	Cost-based Dampening Procedure	No Rescheduling Procedure
System Interruption	Low	←	←	←	High
Modeling Complexity	Low	→	→	High	Low
Developmental Cost	Low	→	→	High	Low
Cost Consideration	NO	NO	NO	YES	NO
Capacity Utilization	NO	NO	NO	NO	NO

Figure 7.1 Major Characteristics of Dampening Procedures

Suggestion for Future Research

There are several important directions in which future research could extend the work of this study. The following are the potential future studies which may generate important results to enhance the body of knowledge regarding MRP system nervousness and dampening procedures.

Investigate the Effectiveness of Local Dampening Procedures to Deal With a Specific Type of Production Uncertainty

Although a local dampening procedure is used to handle a specific type of production uncertainty, it can be an effective technique for some situations. For instance, pegged-requirements can resolve the problem of coverage resulting from a quantity change of the parent items (Orlicky, 1976). However, its effectiveness for lead time compression or time fencing to deal with timing uncertainty is unknown. Therefore, it is interesting to look into the performance of alternative local dampening procedures to tackle a specific type of production uncertainty.

Develop a More Sophisticated Global Dampening Procedure

Campbell (1971) summarized the negative effects of rescheduling as considerable rescheduling cost incurred, fluctuation in capacity utilization, and confusion on the shop floor. The development of cost-based dampening procedure mainly focuses on cost tradeoffs of rescheduling. It is expected that disruption on the shop priority can be reduced to an acceptable minimum by implementing a cost-based dampening procedure. This is because each rescheduling decision is economically justified. The subjective elements of rescheduling decisions are removed so that shop floor foremen should have confidence in priority changes. Nevertheless, capacity utilization at a specific time period is not a design factor in developing the cost-based dampening procedure. Therefore, it should be interesting to develop a capacitated global dampening procedure provided that addition capacity-related information on the shop floor is not very costly to collect.

Figure 7.1 indicates that there is a need to develop a more sophisticated dampening procedure with multiple criteria. That is, cost tradeoffs of rescheduling and capacity utilization may be considered simultaneously. Alternately, capacity utilization may be expressed in terms of capacity change cost, and can be included as part of the cost tradeoffs of rescheduling.

Improve Static Dampening Procedure

From the simulation results, the static dampening procedure is effective under some operating conditions. However, there is still room for this dampening procedure to improve. As discussed previously, the determination of the parameters for "no rescheduling fence" used in the static dampening procedure depends upon the planners' perception of system flexibility in the production system. The degree of system flexibility can vary from time to time. For instance, overtime operation is a major source of system flexibility. The labor supply of a certain industry may experience seasonal fluctuation, which, in turn, may affect the degree of system flexibility. Thus, a static dampening procedure can be developed which periodically updates the parameters used to establish "no rescheduling fence". The continuous revision is made according to the degree of system flexibility detected.

Further, the parameters should not be used for every inventory item to set up a universal "no rescheduling fence". The length of lead time, or even annual dollar usage which reflects the importance of an inventory item, should be considered in establishing a "no rescheduling fence".

Expand Operating Conditions in this Study

Due to time and resource constraints, the experimental design was kept to a four-factor factorial design. Most of the experimental factors contain only two levels. Obviously, future study with different emphasis may be needed to investigate significant experimental factors in depth. The following are the possible extension of experiment environment of the current study.

1. More Lot-Sizing Rules

In this study, EOQ represents the static lot-sizing rule while L4L the dynamic lot-sizing rule. The result may be slightly different, if an alternative lot-sizing rule is used. In order to achieve a more generalized conclusion about the relationship among overall system performance, system nervousness and the nature of lot-sizing rule, more lot-sizing rules should be included.

2. Wider Range of Capacity Utilization Level

Based on the simulation result, the capacity utilization level exerted some impact on the performance of dampening procedures. Again, the turning point of system performance for each dampening procedure in terms of capacity level may be a promising research project. In order to provide insights into this problem, a wider range of capacity utilization level should be included in the experiment.

3. Simulate Different Source of Production Uncertainty

In this study, the sources of production uncertainty were the MPS change along with scrap problem. Other types of uncertain events, such as machine breakdown or equipment malfunction, may be considered.

Conclusion

This dissertation focused on the investigation of the effectiveness of alternative global dampening procedures. A cost-based dampening procedure was developed to compare with the existing ones in terms of total related cost in a number of operating environments. It was found that the selection of an appropriate dampening procedure was sensitive to the capacity level utilized, and the lot-sizing rule used.

This study has attempted to help MRP users select a dampening procedure for their own operating environment. The research objectives defined in this study have been addressed. Several important contributions to practitioners and academicians were also discussed. Some additional areas for future research are identified. The results reported in this study are meant to be a step toward a better understanding of MRP system nervousness.

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