Evaluating the Impact of the Nature of Lot-sizing Rules On MRP System Performance

Chrwan-jyh Ho, Department of Management Science and Information Systems, Spears School of Business, Oklahoma State University, Stillwater, OK 74078, (405) 744-8634, david.ho@okstate.edu

ABSTRACT

Material requirements planning (MRP) system nervousness receives considerable attention in the MRP literature. The causes of system nervousness or scheduling instability in MRP are well recognized. Dynamic lot-sizing rule used is said to be one of the major causes to induce scheduling instability in open orders or planned orders. Furthermore, MRP practitioners suggest that some static lot-sizing rules be used to dampen system nervousness. Economic order quantity (EOQ) is an objective version of static lot-sizing rule to determine constant order quantity. However, most commonly used lot-sizing rules, which include popular lot-for-lot or least total cost, are dynamic in nature whereas the order quantities are changed with time. The purpose of this paper is to examine these general perceptions regarding the effect of the "nature" (static vs. dynamic) of lot-sizing rule on system performance of MRP system via induced system nervousness by a simulation study. A factorial design is used to investigate these research issues under such operating environments as setup/carrying cost ratio, demand variation, and lead time uncertainty. Experimental results reveal that most dynamic lot-sizing rules with exception of lot-for-lot perform significantly better then EOQ rule in terms of a comprehensive cost measurement. Also, the perception that dynamic lot-sizing rules induce frequent scheduling instability than static lot-sizing rules is implausible and is disproved by the results. Furthermore, validation experiments are conducted to verify that the results obtained with these base experiments can be generalized to other limited operating environments.

INTRODUCTION

Material requirements planning (MRP) system nervousness receives considerable attention in the MRP literature. The causes of system nervousness or scheduling instability in MRP are well recognized. Dynamic lot-sizing rule used is said to be one of the major causes to induce instability in open orders or planned orders. Furthermore, MRP practitioners suggest that some static lot-sizing rules be used to dampen MRP system nervousness. Economic order quantity (EOQ) is an objective version of static lot-sizing rule to determine constant order quantity, which is frequently used in MRP systems. In the past decades, there are numerous studies devoted in developing mathematically sophisticated lot-sizing rules. Most of these lot-sizing rules, e.g., Silver and Meal (SM) heuristic method or Wagner-Whitin (WW) algorithm, are dynamic in nature whereas the order quantities are changed with time. However, many of these single-level lot-sizing rules are rarely used because they offered marginal improvement on system performance in real-world multi-level production systems (Theisen 1974; St. John 1984).

The lot-for-lot (LFL) continues to be a popular dynamic lot-sizing rule even though it has been tested as one of the worst rules in either single-level (e.g., Wemmerlov and Whybark 1984) or multi-level (e.g., Biggs 1979; Lee and Adams 1986; Veral and LaForge 1985) MRP systems in most operating conditions examined. The fact that the least work-in-process inventory is carried with the use of LFL makes it one of the favorites of production practitioners (Wemmerlov 1979). Furthermore, as the concept of just-in-time (JIT) becomes widespread in various industries, it is necessary to reduce the setup time to its

possible minimum by using efficient machine tools, fixtures, or material handling systems. It is also well known that the LFL tends to perform well when the setup time is effectively reduced. Therefore, the LFL could still be an important lot-sizing rule for the foreseeable future since small lot-sizes are generally required in JIT production such as Toyota's manufacturing operations.

The purpose of this paper is to examine these general perceptions regarding the effect of the "nature" (static vs. dynamic) of lot-sizing rule on system performance of MRP system via induced system nervousness by a simulation study. A factorial design is used to examine these research issues under such operating environments as setup/carrying cost ratio, demand variation, and lead time uncertainty. Validation experiments are then conducted to investigate whether the results obtained with the base experiment can be generalized to other operating environments. A set of guidelines will be developed to help production planners select an appropriate lot-sizing rule in terms of MRP system performance while minimizing schedule disruptions in their own operating environments.

In the following sections, we discuss the related research briefly. Then, the simulation model is described along with the experimental design, hypothesis statements, and experimental procedure. Finally, along with the future extension related to this paper, the major findings are summarized with managerial implications of experimental results for both practitioners and researchers.

RELATED RESEARCH

There are numerous research papers on the evaluation of lot-sizing performance. Collier (1980) provides an excellent survey of lot-sizing studies that also identify major research issues in lot-sizing studies. Berry (1972) and Kaimann (1969) establish the paradigm for single-level lot-sizing research. Blackburn and Millen (1982), Lee and Adam (1986) and Veral and LaForge (1985), are among the first studies to examine the lot-sizing performance in multi-level production systems. The results obtained from multi-level MRP systems often contradict those obtained by single-level systems (e.g., Blackburn and Millen 1982, Lee and Adam 1986). The difference in simulation settings in these studies may partially contribute to these conflicting results. However, the interdependency between multiple levels in the product structure cannot be ignored in lot-sizing studies that make results in single-level experiments dubious (Wemmerlov 1989).

However, the comprehensive review of lot-sizing studies is not included in this section for it can be found in numerous papers with comparative reviews of lot-sizing rules (e.g., Collier 1980, Ho 1993). Nevertheless, two related research areas are reviewed below.

Lot-Sizing Rules as Causes of System Nervousness

Within MRP systems, inventory-oriented buffering methods such as safety stock or safety lead time are commonly suggested as ways to deal with uncertain events in either single-level or multi-level production systems (New 1975, Whybark and Williams 1976, Grasso and Taylor 1984, Schmitt 1984, Lowerre 1985, Chu and Hayya 1988). MRP system nervousness can be caused by operating variables such as lot-sizing algorithms (Blackburn, Kropp, and Millen 1986) and by environmental factors such as capacity utilization (Mather 1977, Peterson 1975, Steele 1975) or forecast errors (Lee and Adam 1986, Wemmerlov 1989, Ho and Ireland 1993). Therefore, system nervousness is the result of uncertainty existing within or beyond the production system. Any uncertainty, such as emergency customer orders, could cause planned orders or open orders to be rescheduled in MRP systems because of the necessity to maintain up-to-date priorities. It is impossible to come up with a comprehensive study to see which

causes are most severe in terms of causing MRP system nervousness. However, studies have been attempted to investigate individual causes and remedies to deal with the causes or cope with the resultant schedule instability. Among all the causes of system nervousness, the use of lot-sizing rules seems to be the one that receives most attention.

In a comprehensive review of supply uncertainty in MRP environments, Dolgui and Prodhon (2007) focus on parameterization of MRP system, including the use of lot-sizing rule, under demand and lead time uncertainties. Jeunet and Jonard (2000) maintain that frequent revision in demand forecast leads to scheduling instability. They evaluate nine lot-sizing rules based on cost-effectiveness and robustness criteria and conclude that Silver-Meal and Part-Period Balance rules constitute good trade-offs between these two criteria. The failure of EOQ to be robust based on the results contradicts with the finding by Carlson et al (1979).

Using mixed integer linear programming (MILP), Kazan, Nagi and Rump (2000) revise SM and WW algorithms to compare with several popular lot-sizing rules in a rolling horizon. They show that MILP can be effective in some cases in which a production system is not flexible to cope with quantity changes in production schedule. In operating environments characterized by short lead time and inaccurate forecast, Bai et al. (2002) find that system instability is insensitive to the lot-sizing rules used. Their results show that period-order-quantity rule is superior to LFL in terms of service level and total cost.

In view of production uncertainty, there are several lot-sizing studies intended to reduce the resultant system nervousness. Blackburn et al. (1986) evaluate the performance of several dampening strategies, including master production schedule (MPS) freezing and the LFL lot-sizing rule to reduce system nervousness under various operating environments characterized by different cost structures and demand variations. They conclude that the strategies incorporating a penalty cost to discourage schedule changes or freezing the schedule within the planning horizon appear to be dominant under most of the conditions tested. The use of LFL turns out to be an inferior method to reduce system nervousness. In a comprehensive review of uncertainty in MRP systems, Koh, Saad and Jones (2002) suggest that safety stock, the use of appropriate lot-sizing along rescheduling are the most robust methods to cope with MRP uncertainty.

Nature of Lot-sizing Rules

As discussed earlier, numerous lot-sizing studies have conducted to compare the performance of lot-sizing procedures for the finite-horizon at a single-level MRP system. Relatively few lot-sizing studies have recognized the effect of the nature of lot-sizing rules on MRP system performance. Peterson (1975) suggests that the LFL rule or other dynamic lot-sizing rules be used at the upper levels in the product structure while a “constant” lot-sizing rule such as fixed order quantity be used in the lower levels in order to resolve rescheduling problems. Nevertheless, this suggestion may be a subjective judgment based on, at best, several observations of real-world operations. Thus, the claim that the static rules are better to handle rescheduling problems will be examined by a simulation experiment in this study.

Carlson, Jucker, and Kropp (1979) propose the use of dynamic lot-sizing rules that incorporate the "cost of nervousness" in the traditional cost measurement, the sum of set-up and carrying costs, to dampen the planned order nervousness. Hu and Munson (2002) examine lot- sizing rules whereas product price

schedules follow incremental quantity discounts. Ho, Chang and Solis (2006) propose two dynamic lot-sizing rules, which modify the average period cost concept from Silver and Meal algorithm for a single-level uncapacitated lot-sizing study. They show that both proposed dynamic rules produce average carrying and setup costs lower than or equal to those of least period cost rule in every experimental condition tested. This paper extends the previously mentioned works by:

(i) We focus on the examination of the impact of the nature of lot-sizing rules on the system performance of a multi-level MRP system under such stochastic operating environments as lead time uncertainty, cost structure, and demand variation.

(ii) We also investigate the problem of induced frequent rescheduling by static or dynamic lot-sizing rules to see if a deteriorated system performance as measured by a comprehensive cost measure.

RESEARCH DESIGN

The purpose of this paper is to examine these general perceptions regarding the effect of the nature (static vs. dynamic) of lot-sizing rule on system performance of MRP system via induced system nervousness by a simulation study. The experimental vehicle in this paper is a multi-level MRP simulator based on a weekly regenerative MRP system. Two types of simulation experiments are conducted in this paper, the base experiment and the validation experiment. The base simulation experiment is designed to achieve the research objectives defined previously. Due to the exploratory nature of this study, a full factorial design that includes four experimental factors is used as seen in Table 1. Then, separate validation experiments are conducted to verify the simulation results obtained by the base experiment.

The description of the experimental design along with the justification of the experimental factors and levels is presented next, followed by performance measures, research hypotheses, and the experimental procedure.

Factorial Design for Base Experiments

The factors used in the base experiments are presented and the experimental levels are discussed below.

(A) Lot-sizing Rule (LS): Six lot-sizing rules are considered here:

(1) economic order quantity (EOQ), which releases multiples of EOQ value,
(2) lot-for-lot (LFL),
(3) part-period balancing (PPB) with look-forward/look-back feature,
(4) least total cost (LTC),
(5) Silver-Meal discrete lot-sizing heuristic (SM), and
(6) Wagner-Whitin algorithm (WW).

It should be noted that EOQ is the only static lot-sizing rule considered in this study. It is mainly because EOQ should be the best static rule. Other static rule such as fixed order quantity rule relies on the subjective judgments of production planners or shop floor foreman to determine the constant order quantities. At least, the tradeoffs between carrying cost and setup cost for individual inventory items are considered to calculate the size of orders. It is necessary to include the arguably most popular dynamic

rule, LFL, to evaluate the impact of the nature of lot-sizing rules. The other dynamic rules are selected because they are commonly tested in comparative lot-sizing studies (Veral and LaForge 1985). The detailed description of these rules can be found in some past lot-sizing research (e.g., Collier 1980, Wemmerlov and Whybark 1984). Since the intent of this study was not to develop a new lot-sizing rule and compare it with other existing rules, some of the recently developed rules, such as the simple incremental rule (Veral and LaForge 1985), were not included.

(B) Demand lumpiness (DL): The MRP system is capable of handling an MPS with a lumpy demand pattern. The lumpier the demand requirements, the greater the difference between each period's demand and the greater the number of periods with zero demand (Wemmerlov and Whybark 1984). The normal distribution is used to generate different demand patterns with a coefficient of variation (C_v) equal to 0.3 and 0.8. The end-item demands are generated randomly from a normal distribution with a mean of 100 units and then truncated at 0 units. The combination of truncation and different standard deviations ensures different degrees of lumpy demand in the MPS. The inclusion of this factor allows investigation of the impact of demand lumpiness on the schedule instability due to the use of different lot-sizing rules.

(C) Lead time uncertainty (LTU): LTU is also defined by the coefficient of variation (C_v) of the deviation of "Actual Lead Time" (*ALT*) from "Planned Lead Time" (*PLT*). In our simulations the *ALT*s are generated as:

$ALT = PLT * (1 + r\, C_v)$, where $r \sim N(0,1)$ is a standard normal variate. (1)

Levels of C_v considered in this study: 0.2 and 0.4

(In the occasions where $ALT < 0$, we set $ALT = 0$.) Schmitt (1984) considers similar C_vs to specify uncertainty levels in lead time fluctuations. Uncertainties in lead time and demand are still two important variables with which production professionals need to contend.

(D) Setup/carrying cost ratio (CR): This ratio is considered at three levels: 100:1, 300:1, and 500:1; the carrying cost is expressed in terms of $/unit/time period. These levels fall within the range of the cost ratios used in earlier lot-sizing studies (e.g., Berry 1972, Collier 1980, Veral and LaForge 1985) that demonstrate the relevance of the range of the cost ratio in studying MRP system performance.

Performance Measures

Since the objective of this study is to examine these general perceptions regarding the effect of the nature (static vs. dynamic) of lot-sizing rule on system performance of MRP system via induced system nervousness by a simulation study. The comprehensive performance measure considered in this study is the total cost (TC), defined as the sum of inventory carrying cost, setup cost, and rescheduling cost. The TC is a comprehensive measure for assessing a production system's ability to manage inventory levels and plant operation.

$$TC = \sum_i \sum_j H_{ij} + \sum_i \sum_j S_{ij} + \alpha * \left(\sum_i \sum_j WR_{ij} \right) \qquad (2)$$

where:

H_{ij} = carrying cost for the ith inventory item in the jth period;
S_{ij} = setup cost for the ith inventory item in the jth period;
WR_{ij} = weighted rescheduling measure; and
α = weighting factor for rescheduling cost, which is set at $0.001.

Equation (3) is used to calculate the weighted rescheduling (WR_{ij}) measure.

$$WR_{ij} = Q_{ij} * \left| NDD_{ij} - PDD_{ij} \right| \qquad (3)$$

where:

WR_{ij} = weighted rescheduling measure for the ith item in the jth period,
Q_{ij} = the order quantity of the open order of item i in the jth period to be rescheduled,
PDD_{ij} = the prior due date of item i in the jth period, and
NDD_{ij} = the new due date of item i in the jth period.

Since the major focus of environmental uncertainty is timing uncertainty in this study, the quantity changes in an open order will be excluded from the calculation of WR_{ij}. Ho, Carter, Melnyk, and Narasimhan (1986) maintain that quantity changes in open orders should be avoided if at all possible because they can easily be handled by rescheduling open orders. It should be noted that the shortage cost is not considered in the TC. This is because rescheduling or expediting is used to achieve a 100 percent service level. Thus, the rescheduling cost can be viewed as the cost penalty resulting from rush orders. Therefore, the rescheduling cost is the cost trade-off to obtain this service level.

Hypothesis Statements

The main thrust of this paper is to evaluate the nature of lot-sizing on the performance of MRP systems. The formal hypothesis statements are stated as follows. Briefly, the first hypothesis examines the main effect of the nature of lot-sizing rules on MRP system performance. The remaining hypotheses investigate the interaction effects between lot-sizing rules and the other experimental factors on the performance measures.

Hypothesis 1: For a given operating environment under study, there is no significant performance difference among various lot-sizing rules tested in terms of the nature of lot-sizing rules.

Hypothesis 2: For any level of lead time uncertainty, there is no significant performance difference among various lot-sizing rules tested in terms of the nature of lot-sizing rules.

Hypothesis 3: For any degree of demand lumpiness, there is no significant performance difference among various lot-sizing rules tested in terms of the nature of lot-sizing rules.

Hypothesis 4: For any given setup/carrying cost ratio, there is no significant performance difference among various lot-sizing rules tested in terms of the nature of lot-sizing rules.

Hypothesis 5: For a given operating environment under study, there is no significant difference to induce scheduling instability among various lot-sizing rules tested in terms of the nature of lot-sizing rules.

[Experimental Procedure and Assumptions, Data Analysis, and References are available from the author upon request]