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A STRUCTURED ANALYSIS OF MRP SYSTEMS UNDER SUPPLY UNCERTAINTY

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ABSTRACT

One of the major issues affecting the real life performance of MRP is the existence of uncertainties in the manufacturing environment. Lead time uncertainties arising from supplier behavior and process unpredictability are examples of such phenomena. This paper presents an analysis of the operation of MRP systems in the presence of supply and process uncertainties. A simulation model is employed to explore the influence of such uncertainties and their interaction with other factors. The shape of the product structure and the lot-sizing technique used are found to significantly impact performance in the presence of supply uncertainties.

INTRODUCTION

MRP system implementations in manufacturing have often failed to meet expectations. Many explanations have been offered for this failure. One of the major difficulties which hinders the successful operation of MRP systems is the uncertain nature of the manufacturing environment. This uncertainty is due to two major sources, viz., variability in demand and supply variability.

The implementation benefits of research directed to complex manufacturing environments involving supply and demand uncertainties has been recently highlighted by Bahl et. al.[1]. Nearly all simulation studies in the literature focus on demand variability. Supply variability, in terms of the production process, has been relatively unstudied [13]. This paper addresses the latter.

The complicated nature of the general problem of determining optimal ordering policies in a given manufacturing environment has lead many researchers to use simulation techniques in studying the performance of production control systems. For example, Krajewski et. al.[15] have used computer simulation to study the performance impact of MRP, Just in Time and reorder point systems.

Simulation experiments allow researchers to consider variables common to the MRP system (e.g. lot-sizing rules) as well as those common to the manufacturing environment (e.g. product structure) simultaneously, thus providing relatively quick insights into MRP performance. These studies have tended to focus on deterministic lead times and demands [2][3][4][5][6][7][10] [11][15][19].

Whybark and Williams [20] outlined a framework for investigating uncertainty in MRP. This work compared the use of safety stock and safety lead time to protect against uncertainty in demand and supply for a single level product structure. Other research [9][12][16][18], has focused on uncertainty in demand within an MRP system. These efforts focused on the impact that forecasting error has on MRP system performance and how performance of lot sizing rules change in the presence of uncertainty. DeBodt and Wassenhove's work [12] involved a single level lot sizing study with lead times assumed fixed (certain) and equal to zero. They also considered the impact of safety stock in alleviating the ill effects of uncertain demand. Lee and Everett [16] note that inclusion of product structure is not typical to MRP research and included product structure as a research variable in their study. Lead time was assumed to be fixed and equal to 1 period. Chalmet et.al.[9] considered the impact of engineering changes as well as demand uncertainty. A case study was presented for a printed circuit board factory and a simulation experiment was run to compare various lot sizing rules. Sridharan and Berry [18] have investigated the impact of Master Production Schedule freezing methods under demand uncertainty.

Very little attention has been given to lead time uncertainty as a research variable in MRP. Melnyck and Piper [17] studied the effect that choice of lot sizing rule has on lead time error (the difference between the planned and observed lead times) in an MRP system.

OBJECTIVES

The general objective of this paper is to study the behavior of MRP in the presence of variations in lead times due to unpredictability in supplier behavior and/or process variability. Specifically, an understanding of the effect on MRP performance of a variety of probabilistic lead times scenarios is sought. An understanding of this behavior can lead to the development of strategies to maximize MRP performance in such circumstances.

METHODOLOGY

A simulation model [8] incorporating several routines has been developed to study the effect of the interaction of lead time variability with product structure, choice of lot sizing rules and cost ratios in a multi-level environment. This model which is capable of evaluating a variety of scenarios (including uncertainty in actual demand for end items and in actual replenishment lead times), consists of the following routines:

Input routine:

This routine accepts the details of the product structure(s), initial inventories on hand, scheduled receipts (if any), the parameters of the demand distribution and lead times.

MRP routine:

This routine accepts the details of the actual demand for the present period (that is, forecast demand for the present period plus quantities that are past due) and the forecast demands for the next 19 periods. It performs an MRP explosion and time phasing exercise for 20 periods. Thus, the orders which need to be placed for the various parts, subassemblies etc. are obtained from this routine.

Lot sizing routines:

Ten different lot sizing techniques, (viz. lot for lot, economic order quantity, period order quantity, least unit cost, least total cost, part period algorithm, Silver-Meal Algorithm, economic order quantity with shortages, Gupta-Brennan algorithm, and Wagner-Whitin Algorithm), are available for order sizing [14].

Routine which checks the feasibility of MRP output and implements it accordingly:

This routine takes the orders generated from MRP and schedules their receipts based on the lead times and subject to the availability of the siblings.

Updating routine:

This routine provides the demand data for the present period and also advances the simulation time by one period.

Output routine:

This routine calculates period by period statistics and end of simulation run statistics. These statistics cover service level, average back-order and inventory levels, maximum and minimum back-order and inventory levels, and the number of periods back-orders were experienced during the simulation run. Finally, the total cost is calculated based on the number of set ups, the average inventory and average shortage levels.

RESEARCH VARIABLES

A series of simulation experiments were conducted incorporating the following research variables and characteristics:

Product structure:

One of the hypothesis considered is that the attributes of the product structure(s) can influence the performance of MRP. Product structure encompasses several attributes, e.g., number of unique components, number of total components, parent/sibling configuration and shape. In this study four product structures were considered [8]:
i. Rectangular Structure
ii. Pyramid Structure
iii. Triangular Structure
iv. Diamond Structure

Each one of these structures had 21 different items including the end item and six levels including level 0. The major difference between these product structures is in the distribution of the 21 different items among various levels.

To study the effect of parent/sibling configuration two versions of each product structure were used, viz. Chinese (S - single sibling) and Western (M - multiple sibling). The Chinese model represents a product structure where each parent item has only one of each sibling while the Western model has two siblings for each parent item.

Costs:

Each product structure variant is tested using three setup to holding cost ratios, viz., 24,60 and 150, and a fixed shortage cost of 2.

Lead Time Variability:

Lead time variability is applied
i. to each level, individually,
ii. to all levels simultaneously, and
iii. to none of the levels (deterministic case).

This makes eight separate experiments for each product structure variant corresponding to possible sources of lead time variability. For example, when lead time variability is applied to level six, this could represent supplier variability. By contrast, when lead time variability is applied to level one, this could represent variability in the time to complete the final assembly process.

Furthermore, six lead time bias factors (providing for various degrees of lateness in the lead times) are used to generate different patterns of lead time variability. Lead time variability follows a uniform distribution with each bias factor representing a different set of parameters.

Lot Sizing Rules:

Lot sizing is concerned with determining the timing and magnitude of orders to satisfy demand. The benchmark of the lot sizing techniques, in the deterministic environment, has long been the Wagner-Whitin algorithm. However, because of its complex solution procedure involving dynamic programming, it has not been widely implemented in practice. Of the numerous lot sizing techniques developed for the discrete demand situation the following more familiar ones have been included in this study:
i. LFL (Lot for Lot)
ii. EOQ (Economic Order Quantity)
iii. POQ (Period Order Quantity)
iv. LUC (Least Unit Cost)
v. LTC (Least Total Cost)
vi. PPA (Part Period Algorithm)
vii. S-M (Silver-Meal Algorithm)
viii. W-W (Wagner-Whitin Algorithm)

Demand:

Demand was generated sing a uniform distribution between 40 and 60. A planning horizon of 20 periods was employed. Demand uncertainty was not considered in this study, i.e., once the demands were generated they were not altered.

EXPERIMENTATION

To investigate the impact of lead time variability in the multi-level environment with deterministic demand, a total of 9216 scenarios were investigated. Theses scenarios arise from the use of four product structures, two parent/sibling configurations, eight sources of lead time variability, three set up to holding cost ratios, eight lot-sizing rules, six lead time bias factors and one shortage cost.

Each simulation experiment was run for 800 periods. However, in order to attain steady state conditions, the results presented below are based on the last 500 periods' simulation output. The output generated from the first 300 periods' simulation is discarded.

ISSUES EXPLORED

Various attributes of product structure, lot sizing rules and lead time variability are explored for each of the setup to holding cost ratios in a multi-level environment.

Specifically, the issues that are studied pertaining to these attributes include:

- The effect of the shape of the product structure with no lead time variability present.
- The effect of the lot sizing rule employed with no lead time variability present.
- The effect of the shape of the product structure with lead time variability present at all levels of the product structure.
- The effect of the lot sizing rule employed with lead time variability present at all levels of the product structure.
- The effect of changing the distribution of the lead time variability when lead time variability is present at all levels of the product structure.
- The effect of the shape of the product structure with lead time variability present at only one level of the product structure at a time.
- The effect of the level at which the lead time variability is present when lead time variability exists at only one level of the product structure at a time.
- The effect of the lot sizing rule employed with lead time variability present at only one level of the product structure at a time.
- The effect of changing the distribution of the lead time variability when lead time variability is present at only one level of the product structure at a time.

RESULTS OF EXPERIMENTS

Data was collected on both cost and service level performance for each of the 9216 simulation scenarios. Since the maximum value of the service level is one (representing on time performance) and is achieved by many of the scenarios considered, the service level forms a truncated distribution. However since the cost data is not inhibited by such an upper limit (and hence the Normal distribution can be assumed), the analysis focuses on the cost performance data. Further, the natural log transformation was utilized for the cost data to stabilize the variance (heteroscedasticity). This transformed value of cost was used as the dependent variable in the analysis of variance.

Instead of absolute cost, a cost index was utilized for the multiple comparison tests. A separate cost index base was obtained from the results of the experiments for each of the three cost ratios in the deterministic environment. The index base is set at the minimum cost performance obtained in each case, viz., W-W for low to mid setup to holding cost ratios and PPA for the high setup to holding cost ratios. For example, the mean cost obtained in the deterministic environment for the low setup to holding cost ratio, in the case of EOQ was 44915.5 while the lowest mean cost in this same environment was that of W-W whose value was 24000. Thus, EOQ's cost index is 44915.5/24000 or 1.871. The same index bases are utilized in the non deterministic environments.

To investigate the issues raised earlier, an analysis of variance was performed for each of the three cost ratios for deterministic lead time and both versions of lead time variability, viz., lead time variability present at all levels and lead time variability present at only one level at a time. For those factors which are found to significantly impact the performance, Tukey's test for multiple comparisons can be performed.

Based on the statistical analysis described above, the following conclusions were drawn in relation to the issues specified above.

- The shape of the product structure was found to be insignificant with no lead time variability present.
- The lot-sizing rule employed was found to be significant with no lead time variability present.
- The shape of the product structure was found to be significant with lead time variability present at all levels of the product structure.
- The lot-sizing rule employed was found to be significant with lead time variability present at all levels.
- The change in the distribution of the lead time variability was found to be significant when lead time variability was present at all levels of the product structure.
- The shape of the product structure was found to be significant when lead time variability was present at only one level of the product structure at a time.
- The level at which the lead time variability was present was found to be significant when lead time variability was applied at only one level of the product structure at a time.
- The lot sizing rule employed was found to be significant when lead time variability was

present at only one level of the product structure at a time.

o The change in the distribution of the lead time variability was found to be significant when lead time variability was present at only one level of the product structure at a time.

CONCLUSIONS

Because of its structured nature, this study identifies in a systematic way, the impact of lead time variability on MRP performance and its interactive effects with other factors.

The choice of lot-sizing rule impacts performance under all conditions (i.e. with or without lead time variability). The shape of the product structure is only significant in the presence of lead time variability. Changing the distribution of the lead time variability significantly impacts performance. The level at which the lead time variability occurs is also significant when lead variability is applied to only one level of the product structure at a time.

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