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Evaluating the Cost Impact of Forecast Errors and Cost Structure Sensitivity Analysis under Various Prodcut Structures for MRP

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ABSTRACT

The capability of material requirements planning (MRP) as a management information system for world class manufacturing is widely recognized. This study extends previous work by increasing the complexity of product structures and conducting sensitivity analysis on cost structures. For the more complex product structures introducing forecasting error into the master production schedule by positively biasing the forecast reduces total costs. Biasing forecasts is especially effective when stockout costs dominate carrying and ordering costs in the total cost structure. The cost structure sensitiviity analysis shows that: (1) when shortage cost is reduced the cost curve related to underforecasting (forecast less than demand) shifts downward, and vice versa; and (2) when carrying cost is reduced the cost curve shifts downward. The magnitude of change related to overforecasting (forecast higher than demand) is greater than the magnitude of change related to underforecasting.

Keywords: Production and Operations Management, Material Requirements Planning, Systems Simulation

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1. Introduction

Computer supported material requirements planning (MRP) is prevalent in mature production and material functions throughout European and North American manufacturing. One can only speculate as to the speed at which Pacific-Rim manufacturers are integrating MRP computer information systems into their just-in-time (JIT) material planning. In North America just the opposite is occurring. Manufacturers who are MRP users are modifying approaches as they incorporate JIT into their production and inventory practices (Karmarkar, 1989). The speed at which that is happening remains conjective as well.

The capabilities of MRP as a management information system that stores and tracks information on thousands fo products with differing structures (bills-of-materials) are apparent to any world-class manufacturer. Understanding this encourages a continued study of MRP systems under more complex conditions, conditions which approach actual application.

The purpose of this research is to evaluate material requirement planning (MRP) systems when forecast errors are introduced into end prodcut demand through the master production schedule. More specifically, complex product structures and lot-sizing rule selection will be evaluated in the context of introducing planned forecast bias into the MRP system. Then cost structure sensitivity analysis will be implemented to pursue insights.

1.1 Previous Research

Lee and Adam (1986) extended previous investigations into lot-sizing rules (Biggs, 1979) and forecast error (Biggs and Campion, 1982) in material requirements plannning (MRP) systems. Lee, Adam and Ebert (1987) continued to evaluate forecast error in MRP systems, building on previous work. Veral and Laforge (1985) and more recently Wemmerlov (1989) have further explored lot-sizing rule preformance in multi-level inventory systems such as MRP.

The issue of MRP nervousness has been observed in application, and partial solutions have been suggested in guides prepared by users. Academics have suggested that modifying lot-sizing rules to incorporate schedule change costs would reduce MRP nervousness (Kropp, Carlson, and Jucker, 1979; Kropp and Carlson, 1984). More recent extensions have determined that freezing the schedule within the planning horizon eliminated MRP nervousness but increased inventory cost substantially (Blackburn, Kropp, and Millen, 1985 and 1986; Zhao and Lee, 1993).

Sridharan, Berry, and Udayabhanu (1987 and 1988) developed a method of measuring master production schedule stability under rolling planning horizons. Their work investigated the impact of freezing parameters upon total inventory cost and schedule instability in single-level MRP systems under deterministic demand (Sridharan and Berry, 1989). As in the earlier work by Kropp et al., freezing reduced schedule instability (nervousness), but again at the expense of increased inventory cost.

In a general sense, and perhaps over simplifying, these studies in aggregate conclude: (1) lot-sizing rule selection as measured by low cost is impacted by forecast error, the complexity of the product structure, and the cost structure of the MRP system; (2) introducing a positive planned bias into the forecast slightly reduces total cost (improves performance) across various lot-sizing rules, good lot-sizing rules being part period balancing and period order quantity; and (3) reducing MRP nervousness can be achieved, but at the expense of increased inventory cost.

Most relevant to this study are the work of Lee and Adam (1986) and Wemmerlov (1989), both of which examine lot-sizing under conditions of demand uncertainty as expressed by introducing forecast errors. Wemmerlov reaffirmed previous research that lot-sizing rule selection differs under conditions of known demand and conditions of uncertainty. In the former, the Wagner-Whitin optimal solution was best, while in the later the part period balancing rule was superior.

2. Research Issues and the Experimental Procedure

2.1 Research Issues

This study directly extends the work of Lee and Adam (1986). They found (1) the greater the forecast error the greater costs and shortages, (2) the lot-sizing rule and the product structure impact costs and shortages, and (3) in lot-sizing the period ordering rule was the superior rule, but only slightly better than the part period balancing rule. They suggested that the more complicated the product structure, the greater differentiation among lot-sizing rules and the greater the impact of forecast errors.

In this study we are interested in exploring a wider range of product structures, especially more structures with more levels and more interaction among sub-components in the bill-of-material. Additionally, we are interested in utilizing a modified cost structures that more realistically reflects the value added of inventory carrying costs at each level having component parts (Benton and Srivastava, 1985). Finally, cost structure sensitivity analysis is explored.

Formal statement of the hypotheses are provided as Table 1. Hypotheses 1-6 are essentially a replication from the Lee and Adam (1986) study, but with more complex system structures and realistic costs. The first four hypotheses address the impact of forecast error on cost, lot-sizing rule selection, and system structure. The fifth abd sixth hypoteses focus on lot-sizing urles rather than forecast error (hypotheses 1-4). Hypothesis 5 is an overall evaluation of lot-sizing rules while hypothesis 6 focuses on lot-sizing rule performance as impacted by forecast error and system structure. Hypothesis 7 addresses increased system structure complexity, while hypothesis 8 investigates value added inventory carrying costs.

2.2 Experimental Procedures

Computer simulation models were constructed for the MRP systems. Enditem demand forecasts and the associated errors (randomly generated) were introduced into the master production schedule (MPS). Then, over the simulated planning horizon, the realized forecast errors were measured as were the costs of production operations. The simulation runs were conducted on an IBM 4341 computer. The CPU time for a complet simulation for the design below varied from 64 to 109 minutes, increasing with increased system structure complexity.

In the simulation, several procedures need to be discussed so the reader could replicate the study. They relate to the planning horizon, batch sizes, the perpetual inventory procedure, and the questions of MRP nervousness.

The planning horizon is implicitly considered in the study. It depends on the lot-sizing rule used, cost structures (carrying cost, setup cost) of the components in the product structure, and the forecasted demand beyond the total production lead time. The lot-for-lot rule requires one period beyond the total production lead time. The economic order quantity, period order quantity, and part period balancing rules depend upon the forecasted demand and the cost structures of the components in the bill of materials (BOM).

TABLE 1
Formal Statement of Research Hypotheses

Hypothesis	Statement of Hypothesis
	IT IS HYPOTHESIZED THAT IN MRP PRODUCTION-INVENTORY SYSTEMS
1	using heuristic lot-sizing rules the impact of forecasting error upon system performance is significant and, furthermore, the greater the forecasting error the higher the total cost.
2	using heuristic lot-sizing rules the impact of forecasting error upon system performance is contingent upon which lot-sizing rule is used.
3	using heuristic lot-sizing rules the impact of forecasting error upon system performance is contingent upon the MRP system structures.
4	using heuristic lot-sizing rules the impact of forecasting error upon system performance is contingent upon both the lot-sizing rules and the MRP system structure.
5	the system's performance is significantly related to the selected lot-sizing rules.
6	the performance evaluation of lot-sizing rules is contingent upon the forecasting errors levels, MRP system structures, and their interactions.
7	the more complex the system structure, the greater system costs and the more difficulty in differentiating among the better lot-sizing rules.
8	value added costing of inventory carrying costs, as compared to no value added costing, does not change performance results in terms of the best performing lot-sizing rules.

Batch sizes related to order releases depend on the forecasted demand in the planning horizon and the lot-sizing rule used.

A perpetual inventory control mechanism is carried out in the simulation. If the total inventory and planned order receipts cannot cover the forecasted demand beyond the total production lead time (within the lead time is considered in this case), then a planned order is triggered in the MPS. Through product explosion, new demand information is updated for all the components in the BOM. The procedure triggers the order releases for the highest level components in the BOM. This is the latest order release of raw materials needed, which can satisfy the planned order release of the finished product on time.

All the planned order releases are frozen if they are related to the order releases of the raw materials. Thus, the planning horizon beyond the relevant planned order releases has no impact upon system performance. The focus in this study is on cost as a measure of performance. Other studies engage in system nervousness research, which was recognized here.

Design of the Experiments

Three independent and one dependent variable, an operations cost, were employed in a series of computer simulation experiments. The indepentent variables – forecast error distribution, lot-sizing rules, and MRP structure – and the dependent variable – a specific operations cost – are described below. Table 2 summarizes the independent variables and their levels.

Forecast Error Distribution. The forecast error distribution for an end item is normally distributed with a specified mean (μ) and standard deviation (σ). The seven levels of the mean and four levels of the standard deviation are illustrated in Table 2. Forecast error is measured by standard deviation and bias, a positive bias reflecting over-forecast and a negative bias reflecting an under-forecast.

Lot-sizing Rules. As shown in Table 2, the lot-sizing rules evaluated in this study are lot-for-lot (L4L), economic order quantity (EOQ), period order quantity (POQ), and part period balancing (PPB).

TABLE 2
Experimental Design Independent Variables

Independent Variables	Level	Description
Forecasting Error		
(a) the mean	1	$\mu = 0$ for error generating function
	2	$\mu = 100$ for error generating function
	3	$\mu = 300$ for error generating function
	4	$\mu = 500$ for error generating function
	5	$\mu =$-100 for error generating function
	6	$\mu =$-300 for error generating function
	7	$\mu =$-500 for error generating function
(b) the standard deviation	1	$\sigma=$ 100 for error generating function
	2	$\sigma=$ 200 for error generating function
	3	$\sigma=$ 300 for error generating function
	4	$\sigma=$ 400 for error generating function
Lot-sizing Rule	1	the Lot for Lot (L4L) rule
	2	the Economic Order Quantity (EOQ) rule
	3	the Period Order Quantity (POQ) rule
	4	the Part Period Balancing (PPB) rule
MRP System Structure	41	the MRP 41 System
	42	the MRP 42 System
	43	the MRP 43 System
	31	the MRP 31 System
	32	the MRP 32 System
	33	the MRP 33 System

MRP Sturctures. Six MRP structures are investigated in this study. Previous studies have incorporated several very simple system structures. Simple structures were not replicated. Instead, these six structures were selected as more representative of actual MRP systems (White, Anderson, Schroeder, and Tupy, 1982). Figure 1 illustrates the system structures.

Operations Costs. Operations costs include inventory carrying costs stated as value added, setup costs, and end-item shortage costs. The total of these costs is used as the primary criterion for performance evaluation. Operating costs are simulated for each time period and evaluated over time.

3. Results

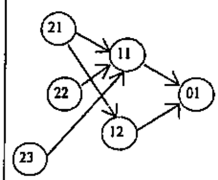
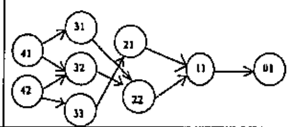
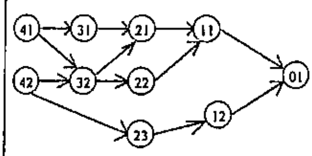
As shown in Table 3 all main effects and two-way interactions were significant at the level p≤0.0001 for the dependent variable total cost. Similar sesults were found for other dependent variables. Table 4 summarizes the results by providing the difference in levels within each independent variable for each dependent variable. Examining the total cost column, for example, indicates the best performance based on lowest total cost would be (1) forecast errors with a slight bias (300 or 500 given a mean of 1000) or a small standard deviation, (2) the period order quantity lot-sizing rule, and (3) MRP system structure 42 or 43. Level differences are determined by Duncan's method at the 0.05 level of significance. The lower the independent variable level in the table, the better the performance of that level. Let's now examine Table 4 more carefully, especially in terms of total cost performance.

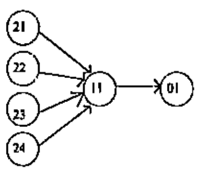
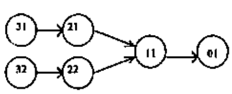
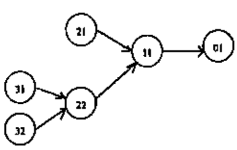
3.1 Lot-sizing Rule Performance

Table 4 ranks the lot-for-lot rule as best based on total carrying cost, the economic order quantity rule as best based on shortage costs and number of shortages, and the period order quantity rule as best based on set-up cost and total cost. Looking more closely at total cost, Table 5 illustrates that although period order quantity provides the lowest cost ($3,104,246), part period balancing is a very close second ($3,192,385). The $88,139 difference seems large, yet as a percentage from the lowest cost there is but a 2.8 percent difference in the two rules.

3.2 MRP System Structure Performance Differences

In Table 4 lowest costs were found for the simpler system structures, 41, 42 and 43 (see Figures 1 and 2). This would be expected. The most complex system appears to be 33. System 33 generally had the highest costs across other variables as noted by its being the top row in the MRP part of Table 4. Actual performance differences as expressed in total cost are shown in Table 6, there being no significant difference in the two total costs for systems 42 and 43.

MRP System	System Structure*	BOM Level
MRP31		3 Levels
MRP32		5 Levels
MRP33		5 Levels

MRP System	System Structure*	BOM Level
MRP41		3 Levels
MRP42		4 Levels
MRP43		4 Levels

* Each circle represents one component. All components are coded by two digits. The first digit represents the level of bill-of-material (BOM) with the final product being coded at the highest (level 0). The second digit represents the component identity in the BOM level.

Figure 1: MRP Systems Structure*

TABLE 3
ANOVA Results for MRP Systems Simulation:
Total Cost as the Dependent Variable

Dependent Variable: TOTCOST

Source	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR>F
MODEL	671	29880757004233685	44531679589022	452.35	0.0001
ERROR	2016	198466459040128	98445664206		
CORRECTED TOTAL	2687	30079223463273813			
R-SQUARE	C.V.	ROOT MSE	TOTCOST MEAN		
0.993402	7.21	313761	4348151.81		

Source	DF	ANOVA SS	F VALUE	PR>F
MRP	5	1908150143331430	3876.55	0.0001
LSR	3	9505336256220866	32184.71	0.0001
LSR*MRP	15	137244004231517	92.94	0.0001
EXBIAS	6	16533905300718802	27991.59	0.0001
EXBIAS*MRP	30	160615159750799	54.38	0.0001
EXBIAS*LSR	18	1428981801249537	806.41	0.0001
EXBIAS*LSR*MRP	90	58608750862414	6.61	0.0001
EXSTD	3	23398398804206	79.23	0.0001
EXSTD*MRP	15	2493176954227	1.69	0.0466
EXSTD*LSR	9	5685071932994	6.42	0.0001
EXSTD*LSR*MRP	45	1924458100292	0.43	0.9996
EXBIAS*EXSTD	18	82730453709591	46.69	0.0001
EXBIAS*EXSTD*MRP	90	10773281086190	1.22	0.0856
EXBIAS*EXSTD*LSR	54	11507865655481	2.16	0.0001
EXBIAS*EXSTD*LSR*MRP	270	9402881625339	0.35	1.0000

TABLE 4
Summary System Performance:
Independent Variables BIAS, Standard Deviation, Lot-Sizing Rule, and MRP Structure*

Dependent Variable / Independent Variable	Total Cost	Set-up Cost	Carrying Cost	Shortage Cost	#of Shortage Times
BIAS	-500	-100	500	-500	-500
	-300	0	300	-300	-300
	-100	-300	100	-100	-100
	0	100	0	0	0
	100	-500	-100	100	100
	300	300	-300	300	300
	500	500	-500	500	500
STD	400	100	400	400	100
	300	200	300	300	400
	200	300	100	200	300
	100	400	200	100	200
LSR′	1	1	2	1	1
	2	4	3	4	3
	4	2	4	3	4
	3	3	1	2	2
MRP	33	33	33	32	33
	32	32	32	41	32
	31	31	31	33	42
	41	41	43	31	43
	42	42	42	42	31
	43	43	41	43	41

* Factor levels are ranked in descending by average value of the dependent variable (the factor with the best performance is at the bottom). Levels are differentiated by Duncan's method at the 0.05 level of significance. Indifference between factor levels is marked by a sidebar.

′ Lot-Sizing rules: 1, lot-for-lot; 2, economic order quantity; 3, period order quantity; 4, part period balancing.

TABLE 5

Lot-sizing Rule Performance*

Lot-sizing Rule	N	Mean Setup Cost	Mean Carrying Cost	Mean Shortage Cost	Mean Number of Time Short	Mean Total Cost	Total Cost Expressed in %
Lot-for-lot	672	4578077	303793	2713376	44.13	7595246	244.67
Economic Order Quantity	672	859693	1039777	1601260	15.18	3500730	122.78
Period Order Quantity	672	700204	724165	1679877	16.10	3104246	100.00
Part Period Balancing	672	932705	577618	1682062	15.90	3192385	102.84

*Factor levels are differentiated by Duncan's method at the 0.05 level of significance. Indifference between factor levels is marked by a sidebar.

TABLE 6

MRP System Structure Performance Difference*

MRP Structure	N	Mean Setup Cost	Mean Carrying Cost	Mean Shortage Cost	Mean Number of Times Short	Mean Total Cost	Total Cost Expressed in %
33	448	2565281	1180021	2034950	24.65	5780252	162.78
32	448	2137574	897596	2156838	23.05	5192008	146.21
31	448	1584377	547520	1892131	22.22	4024029	113.32
41	448	1434998	440644	2086251	21.29	3981892	112.13
42	448	1437895	449423	1672345	22.88	3559663	100.24
43	448	1425895	452828	1672345	22.88	3551068	100.00

*Factor levels are differentiated by Duncan's method at the 0.05 level of significance. Indifference between factor levels is marked by a sidebar.

TABLE 7

System Performance Introducing Forecast Error (BIAS)*

Expected Mean BIAS (EXBIAS)	N	Mean Setup Cost	Mean Carrying Cost	Mean Shortage Cost	Mean Number of Time Short	Mean Total Cost	Total Cost Expressed in %
-500	384	1801635	422379	7284211	68.24	9508225	393.86
-300	384	1880911	517546	4038527	50.03	6436984	266.64
-100	384	1900008	599971	1413253	27.45	3913231	162.10
0	384	1887544	647680	527610	10.65	3062834	126.87
100	384	1802458	697261	163109	3.21	2662828	110.30
300	384	1611633	819928	7294	0.21	2438855	101.03
500	384	1489500	924604	0	0.00	2414104	100.00

*Factor levels are differentiated by Duncan's method at the 0.05 level of significance. Indifference between factor levels is marked by a sidebar.

TABLE 8

System Performance Introducing Standard Deviation*

Expected Mean Standard Deviation (EXSTD)	N	Mean Setup Cost	Mean Carrying Cost	Mean Shortage Cost	Mean Number of Time Short	Mean Total Cost	Total Cost Expressed in %
400	672	1687423	665867	2126292	22.56	4479582	105.49
300	672	1756326	662909	1972174	22.52	4391409	103.41
200	672	1806582	657282	1811367	22.51	4275231	100.67
100	672	1820350	659295	1766741	23.72	4246385	100.00

*Factor levels are differentiated by Duncan's method at the 0.05 level of significance. Indifference between factor levels is marked by a sidebar.

3.3 Forecast Error and Performance

Forecast error was introduced into the master production schedule as indicated by bias or standard deviation. Table 4 indicates that a slight positive bias (300 or 500) provides lower cost than zero or negative bias as judged by all dependent variables except carrying cost. Similarly, a slight standard deviation seems generally better than a larger error. Standard deviation results are more mixed, with total cost suggesting a 100 or 200 standard deviation level as best.

Table 7 provides a closer look at bias and total cost. It is interesting that cost can be improved 21 percent by introducing a bias of 500 to a mean of 1000. This was determined by comparing 0 and 500 bias, i.e. the difference between \$3,062,834 and \$2,414,104 expressed as a percentage. Total cost percentage differences and component costs for forecast error expressed as standard deviation were less than for bias, as summarized in Table 8.

of special interest in this study was the relationship between forecast error bias and system performance measured by total cost and component costs. Figure 2 provides that cost curve for the most complex system structure, system 33, and the best performing lot-sizing rule, the POQ rule. Note that as bias moves from zero to slightly positive, cost continues to lower but then levels off and actually increases slightly.

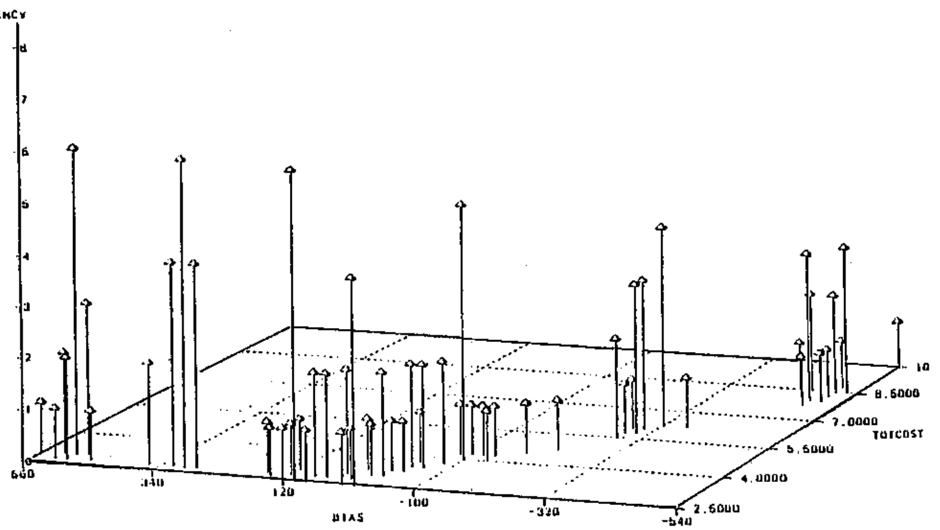


Figure 2: Forecast Error (BISA) and Total Cost (Totcost in Millions): Interactions for a Complex Systems Structure (MRP33) and for the Best Performing Lot-sizing Rule (POQ)

Figures 3-5 provide the cost curves for the total cost components carrying cost, set-up cost, and shortage cost, again with system 33 and the POQ rule. A clear relationship exists for carrying costs and shortage costs. Increasing bias drives up carrying costs, while increasing bias from negative lowers shortage costs until a positive bias is reached. The set-up costs tend to follow carrying costs, yet not so clearly. One has to examine the values of costs on all three figures to understand Figure 2.

Form Figure 3, we observe that carrying cost increases with increasing bias. This occurs because increasing bias increased the batch size for the various lot-sizing rules. This results in larger inventory, hence larger carrying cost.

In Figure 4, the relationshiop between the setup cost and forecast bias shows an inverted U-curve, which is somewhat counter-intuitive. Remember that increasing bias increases the batch size. This results in larger inventory on hand and reduces the frequency of needed setups. Thus setup cost is reduced. On the other hand, decreasing bias decreases the planned production and ignores the needed setups. This reduces the setup cost, although it increases shortage cost. Therefore, the highest cost is at zero bias, as shown in Figure 4.

Figure 5 illustrates that the shortage cost increases as forecast bias becomes more negative. Under extreme positive forecast bias the shortage cost remains zero. When forecast bias is slightly positive there is a dipsersion of observations. Why does this occur? Under extreme positive bias, the system carries large inventory and incurs no shortage cost. When the magnitude of positive bias gets smaller, the forecast error standard deviation may cause shortages. The same is true if the magnitude of negative bias is relatively small. Under extreme negative bias, the more negative bias results in more shortages.

In summary, how do Figures 3-5 shape figure 2? In this cost structure, the shortage costs overshadow the negative effects of a positive bias for carrying and ordering costs. Stated another way, the results in figure 2 are most influenced by Figure 5.

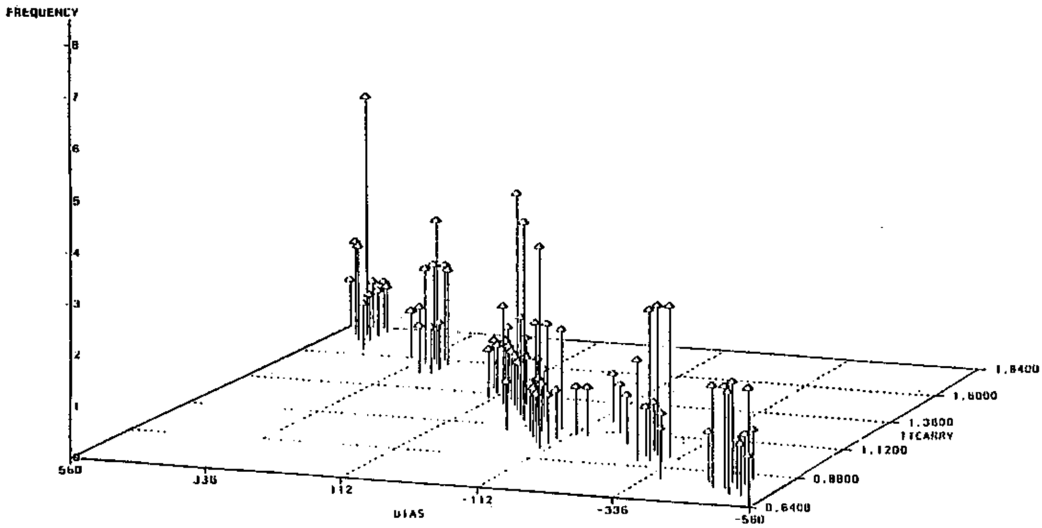


Figure 3: Forecast Error (BIAS) and Total Cost (Ttcry in Millions): Interactions for a Complex Systems Structure (MRP33) and for the Best Performing Lot-sizing Rule (POQ)

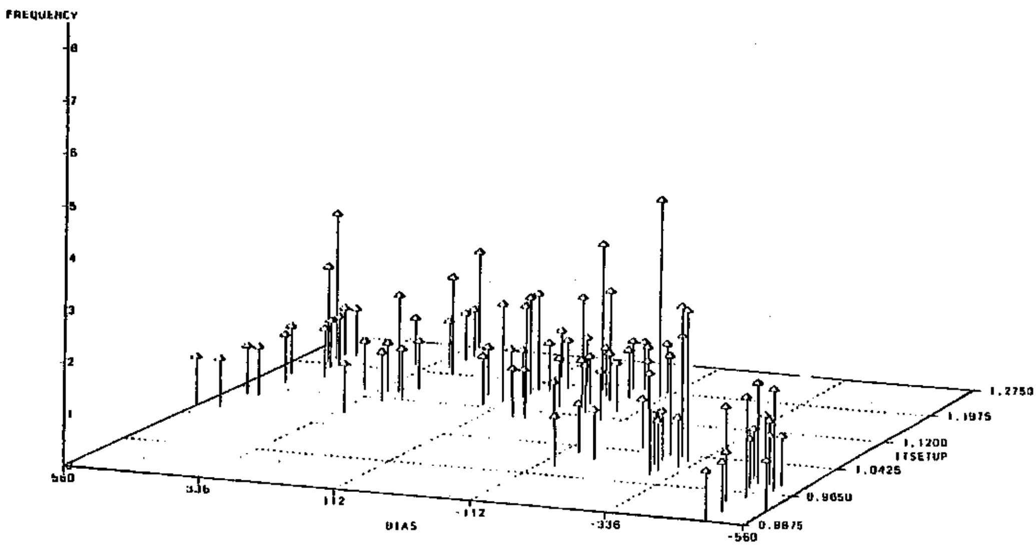


Figure 4: Forecast Error (BIAS) and Total Setup Cost (Ttsetup in Millions): Interactions for a Complex Systems Structure (MRP33) and for the Best Performing Lot-sizing Rule (POQ)

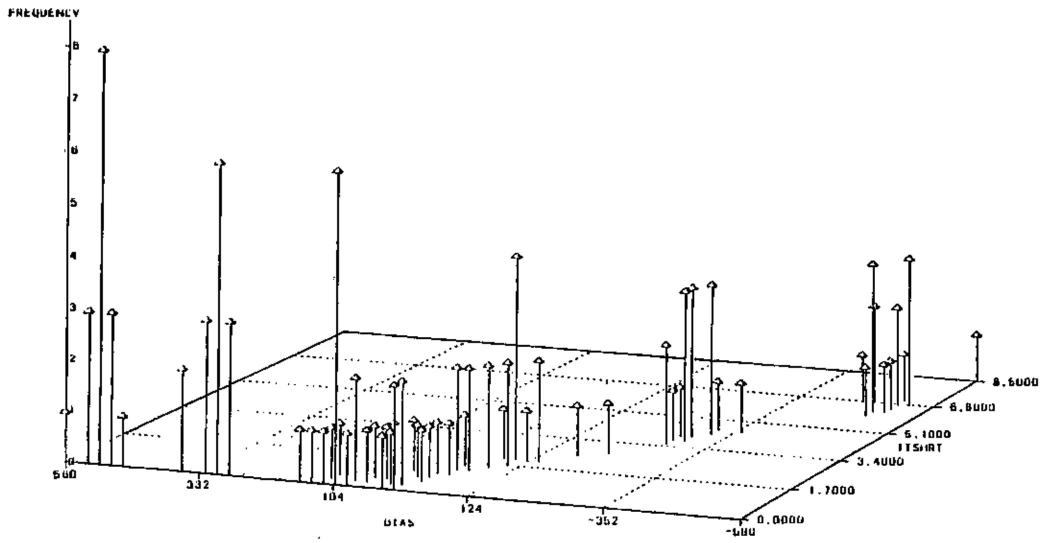


Figure 5: Forecast Error (BIAS) and Total Shortage Cost (Ttshrt in Millions): Interactions for a Complex Systems Structure (MRP33) and for the Bestt Performing Lot-sizing Rule (POQ)

4. Cost Structure Sensitivity Analysis

The objective of this section is to first determine what happens when the cost structure is changed and second to determine the sensitivity of change to changes in cost parameters. All four lot-sizing rules in MRP33 and MRP43 were chosen for the analysis. Every factor but the cost structure remains the same for the cost structure sensitivity analysis. Shortage cost Sensitivity analysis

4.1 Shortage Cost Sensitivity Analysis

The shortage cost for the end item is changed to 50%, 25%, 10%, and 5% of its original cost. An example of total cost curve is presented as Figure 6.

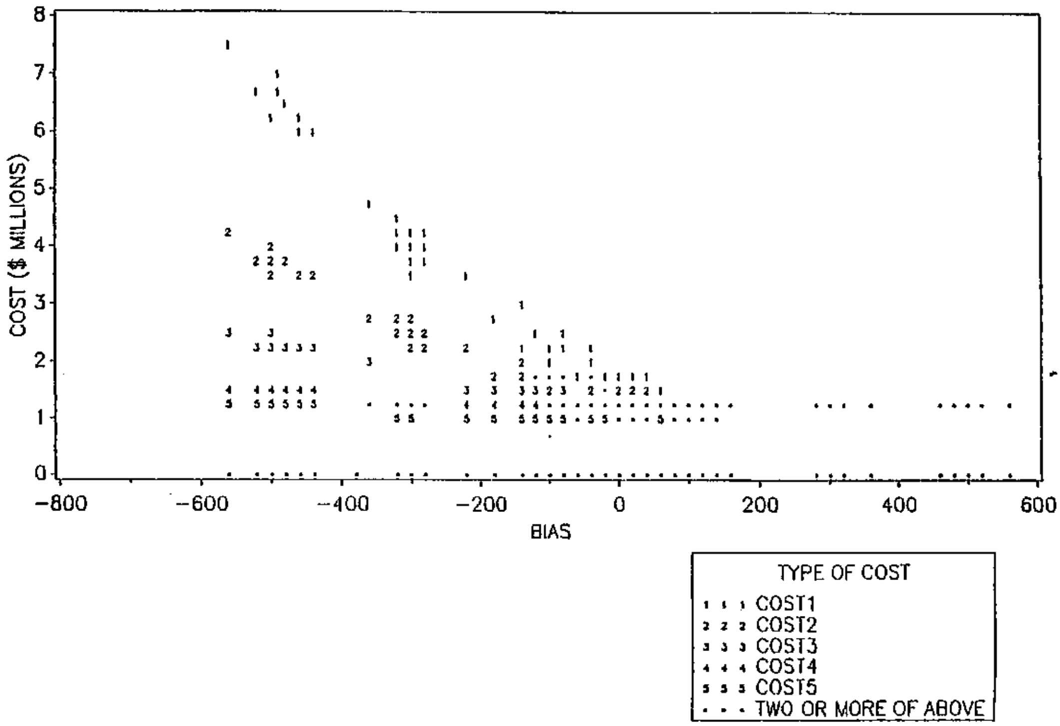


Figure 6: Cost Structure Sensitivity Analysis for Shortage Cost Variations in MRP43 (LSR=4, Part Period Balancing)

See the legend of figure 6 for the symbols depicting shortage cost percentages of the original shortage cost. Cost 1 is the original cost, cost 2 is 50% the original cost, and so forth.

After reviewing plots of all shortage cost curves, we make these observations. As the shortage cost reduces the cost curve shifts downward for the under forecasting portion. The same change has little or no impact for the extreme positive bias portion.

When shortage cost is reduced to 5% or 10% of its original cost, more negative bias results in lower total cost (EOQ, POQ, PPB in MRP33; EOQ, POQ in MRP43). The explanation is that the shortage cost reflects the value or profit of the product. If the shortage cost is too low there is no profit for the product. The system is better off by not making and selling the product.

For the lot-for-lot rule, the total cost increases as the bias gets more negative. This implies the shortage cost still dominates carrying and setup costs. For the PPB rule, the total cost curve implies an optimal planned bias exists between -200 and -400 when shortage cost reduces to 5% of its original cost.

4.2 Carrying Cost Sensitivity Analysis

The carrying cost is increased to 200%, 400%, 600%, and 800% of the original carrying cost for every item in the corresponding MRP structure. The idea is to change the ratio between the setup cost and the carrying cost. Thus, the sensitivity analysis of the setup cost would be redundant and hence was not conducted.

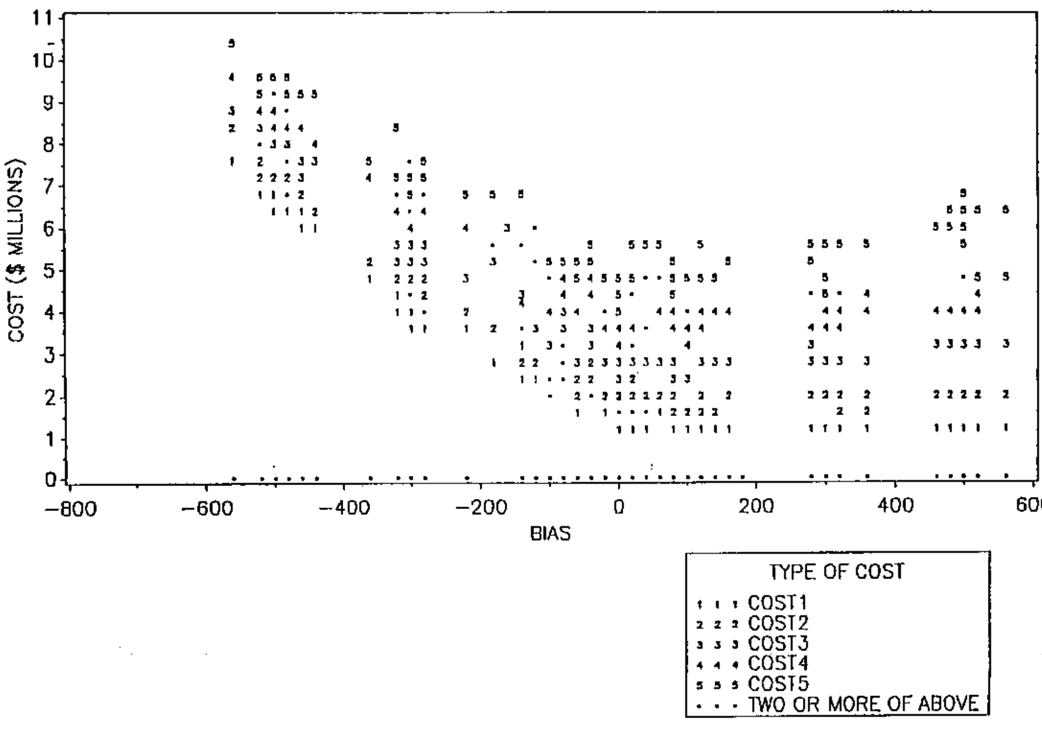


Figure 7: Cost Structure Sensitivity Analysis for Carrying Cost Variations in MRP43 (LSR=4, Part Period Balancing)

An example of a total cost curve is presented as Figure 7. The legend of Figure 7 shows the symbols that represent the percentage increases in the original carrying cost, where cost 1 is the original cost, cost 2 is 200% the original cost, and so forth.

All plots demonstrated that the total cost curve shifts upward. However, the portion related to larger positive bias shifts upward at a sharper slope (rate of change) than the portion related to smaller bias. On the orther hand, the portion related to extreme negative bias shifts upward at a decreasing rate when bias becomes more negative. The minimum cost point shifts toward the left when carrying cost gets larger.

5. Discussion and Conclusions

5.1 Conclusions from the Proposed Hypotheses

The formal hypotheses were stated in Table 1, the first four hypotheses focusing on forecast error. these hypotheses move from a general belief (hypothesis 1) toward a contingency view (hypothesis 4). Hypothesis 4 held, as did hypotheses 1-3. Similarly, when hypothesis 6 is summarized as we did previously, hypothesis 5 results were apparent. These results were consistent with Lee and Adam (1986). Hypothesis 7 held as demonstrated by Tables 4 and 6. As suggested by hypothesis 8, the more realistic value added approach to carrying costs did not provide different results than previous studies. This was shown by comparing hypotheses 1-6 of this study to the Lee and Adam (1986) study.

5.2 Interpretation and discussion

If one is most interested in the cost consequences of poor forecasting and poor lot-sizing rule selection, then this study has some clear suggestions. Let's focus on the results which measure total cost as the preferred performance criterion. The summary in Table 4 allows us to make some suggestions for practicing inventory and production control managers. First, as managers generally understand, the more complex the MRP system as indicated by the number of levels and sub-components in the product structure; the higher the total costs. Given these complex structures as reality, what should the manager do in the decisions he or she can control? For the lot- sizing decision this study suggests period order quantity (POQ) or possibly part period balancing

(PPB) as the lot-sizing rule of choice. Regarding decisions in forecasting procedures, bias introduced as a forecast error into the master prodcution schedule might lower total costs. For a profitable product, we expect this bias to be positive. This is especially so if shortage costs are high compared to carrying and ordering costs.

For those intersected in research issues in material requirements planning (MRP) prodcution-inventory systems, this study generally confirmed previous work (Lee and Adam; 1986; Wemmerlov, 1989). This study increased the complexity of the MRP system structures and introduced more realistic carrying costs (Benton and Srivastava, 1985). Further, the cost curves related to total cost and component cost – such as carrying cost, setup cost, and shortage cost (Figures 3-6) – helped better understand the cost behaviors related to forecast error bias. The cost structure sensitivity analysis demonstrates how the total cost curve responds to the changes in shortage costs and carrying costs. Although the sensitivity analysis provided interesting insights, the conclusions from the formal hypotheses testing remain unchanged.

In conclusion, we are hopeful that continued research into MRP systems will move in the direction of more complex experimental designs. Further, field work in actual MRP manufacturing settings is necessary to explore a wider range of product structures and cost consequences. Well documented case histories in firms would be useful and would surely suggest meaningful experimental questions. Our final thought for the practicing manager is one of caution, as we find the questions of forecast error and lot-sizing rule selection to be complex. Directed trial-and-error via simple simulations in one's own environment might well be worth the time and expense expended.

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