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# A MODEL OF MRP USE AND APPLICABILITY

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ABSTRACT

Though Material Requirements Planning (MRP) has been highly touted as an approach to production and inventory management, success rates for MRP implementation are typically quoted at less than 5%.

The purpose of this paper is to explain major factors affecting the use of MRP, and to build a predictive model of MRP applicability. It is proposed that an important aspect of the lack of MRP success stems from attempts to implement MRP in inappropriate environments. A model of MRP usage in various environments is thus developed, based upon a microeconomic production view of decision-making. Model parameters are estimated using logistical regression based upon data from a survey of production managers and staff. The resulting model provides a number of insights. For example, job shop manufacturing environments with complex product structures tend not to employ MRP. The microeconomic basis of this model allows a translation of MRP usage to MRP applicability. Thus, contrary to MRP proponents, job shop oriented firms with complex product structures seem not to be appropriate environments for MRP implementation.

This paper provides one of the first empirically-based models of MRP usage and applicability. Thus, the conclusions are significant for production managers and production management researchers. In addition, the model building approach can be generalized for use by researchers attempting to evaluate other management information systems or decision support systems.

## 1. INTRODUCTION

Material Requirements Planning (MRP)[1] is an approach to production and inventory management (PIM) which, according to Wight [23, p. 23], has been so successful for manufacturing firms that it has virtually made traditional PIM theory obsolete. Traditional reorder point based PIM attempts to reconcile conflicting goals of minimal inventory investment, minimal shortage caused production delays, and maximized customer service, by focusing upon reorder point techniques (EOQ, etc.) for production and inventory requirements [16, p. 5]. In a typical manufacturing environment, problems with these statistical replenishment approaches stem from violations of their basic assumptions: the dependent demand for production inventories is not independent, is not uniform or continuous, and is not characterized by random fluctuations [15, p. 8].

MRP attempts to reconcile the conflicting manufacturing goals by basing inventory and production requirements upon customer demand (orders and/or forecasts) for finished goods. This demand is then "exploded" via a bill of materials, indicating the timing and quantity of production inventory required. It is this dependency of production inventory upon customer demand for finished goods which invalidates statistical reorder point techniques, but which is purportedly handled by MRP.

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All is not well with MRP, however. As Plossl [17] notes "never... has so much been proclaimed and expected and so little actually delivered". Success rates typically given in MRP literature run at less than 5% [3]. Most diagnoses indicate a variety of problems associated with MRP failure, including resistance to change [21], ineffective production and manufacturing strategies [4], lack of management understanding and commitment to MRP [5], and inaccurate work-in-process inventory accounting [12].

The purpose of this paper is to explain major factors affecting the use of MRP, and to build a predictive model of MRP applicability. It is proposed that an important aspect of the lack of MRP success stems from attempts to implement MRP in inappropriate environments. A model of MRP usage in various environments is thus developed, based upon a microeconomic production view of decision-making [10]. Model parameters are estimated using data from a survey of production managers and staff. The resulting model provides a number of insights. For example, job shop manufacturing environments with complex product structures tend not to employ MRP. The microeconomic basis of this model allows a translation of MRP usage to MRP applicability. Thus, contrary to MRP proponents, job shop oriented firms with complex product structures seem not to be appropriate environments for MRP implementation.

This paper provides one of the first empirically-based models of MRP usage and applicability. Thus, the conclusions are significant for production managers and production management researchers. In addition, the model building approach can be generalized for use by researchers attempting to evaluate other management information systems or decision support systems.

A brief description of the microeconomic production view of decision-making is presented next. This is followed by discussions of the predictive model, its estimation and implications.

## 2. DECISION PRODUCTION SYSTEM

A decision production system (DPS) is postulated to exist, in which functional relationships link the use of certain physical resources (computer software, managers, communications devices, etc.) with the production of decisions. As with normal production, a transformation of raw materials is said to occur. The raw material of decision production is information, transformed from its initial state (data) to its final state (decisions).

The output of a DPS (i.e., decisions) is treated as one of the many inputs to a firm production system. For example, in the manufacture of cars, production planning and control decisions are considered a class of input along with raw materials, equipment, etc.

The DPS is viewed here as a neoclassical microeconomic productive unit, and thus must conform to neoclassical definitions and assumptions. This neoclassical foundation provides both guidance and constraints. These constraints serve to limit the decision contexts within which the DPS framework is appropriate. Applicable contexts tend to be those which are more structured, oriented toward management or operational control, with relatively high decision volume [9, Chapter 4].

This paper's subject, production and inventory management (PIM), fits this type of decision context. The decisions resulting from PIM are considered another class of inputs along with inventory (raw material and work-in-process), physical capacity and non-management labor, which work together to produce a firm's product.

## 3. MODELLING APPROACH

Building upon this DPS foundation, the following discussions develop a model characterizing the use of MRP within various manufacturing environments. The model identifies conditions in which MRP should be used in lieu of the traditional reorder point approaches to PIM.[2] This evaluation is accomplished by comparing the cost of decision making associated with each approach. For a given environment and output level, the least cost approach is considered appropriate. Since the trade off between MRP and reorder point approaches can be viewed as an evaluation of competing technologies, long run average cost comparisons can be used. The choice, then, involves picking that "decision technology" which has the smallest long run average cost at the required decision production level. This choice is illustrated in Figure 1 where $q^*$ represents the critical decision output level, above which MRP should be chosen.[3]

To facilitate discussion, the $q$ in Figure 1 and elsewhere is used to represent a single dimension measure of PIM decisions. This aggregate metric will be called decision quality. (See [10] for a discussion of the many characteristics which decision quality represents.) In the context of this MRP study, higher PIM decision quality can be reflected in:

- master production schedules which are realistic as compared to available capacity
- everything required for production will be available in the right quantities at the right time
- appropriate job priorities
- appropriate solutions to problems causing production delays.

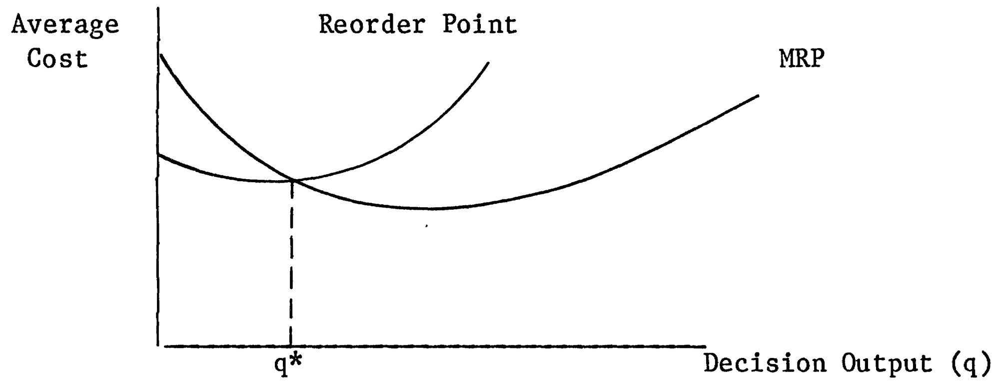


Figure 1. Conceptual View of The Long Run Average Cost Tradeoff Between Reorder Point And MRP Decision Technologies.

## 4. MRP USAGE MODEL FOUNDATION

This section employs the above approach to develop a model of MRP usage. Various factors are identified which affect the MRP and reorder point long run average cost curves, and which determine the required amount of decision quality. The resulting MRP usage model is illustrated in Figure 2, where the following environmental factors are postulated to affect MRP use:

- Environmental conflict with MRP assumptions
- MRP implementation costs
- Environmental conflict with reorder point assumptions
- Reorder point implementations costs
- Firm production volume
- Relative productivity of PIM decisions.

These factors are posited to impact MRP use through their effects upon three intervening variables: long run average costs for reorder point and MRP approaches, and decision quality level. The model is discussed in more detail below.

The posited effect upon long run average costs of environmental conflict with MRP assumptions is illustrated in Figure 3. Here $MRP_0$ represents the long run average cost curve for PIM, using MRP with no assumption violations. $MRP_1$ represents the same cost function with one MRP assumption violation. More assumption violations are expected to further shift the cost curve to, for example, $MRP_2$. Upward shifts in the long run average cost curve imply a greater cost to obtain a given amount of decision quality. This link between the violation of a model's assumptions and increased costs can be thought of in terms of increasingly sophisticated MRP implementations. For example, MRP assumes deterministic finished goods demand. Decreases in decision quality due to increased finished goods demand randomness may be offset by more frequent "regeneration" of

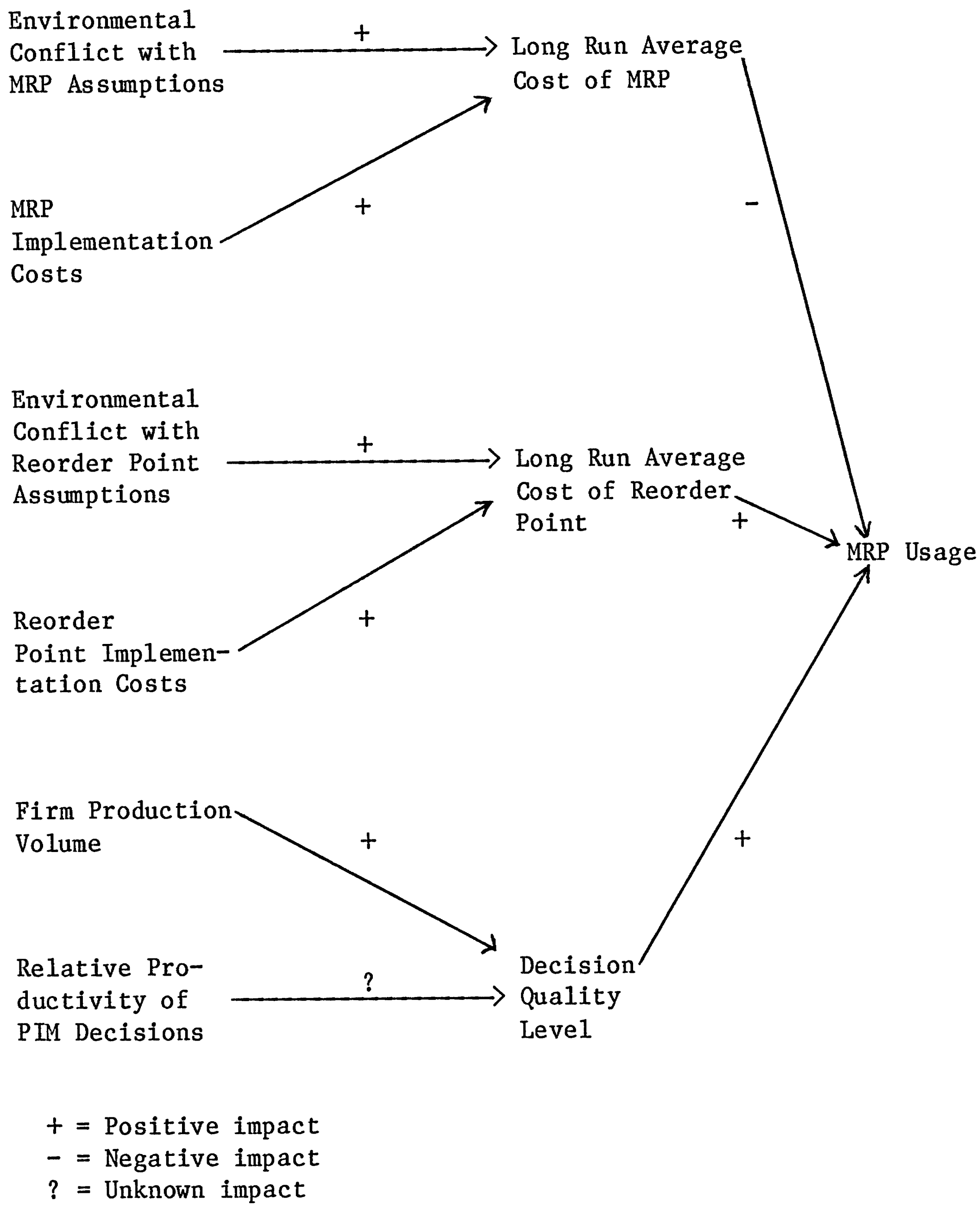


Figure 2. MRP Usage Model

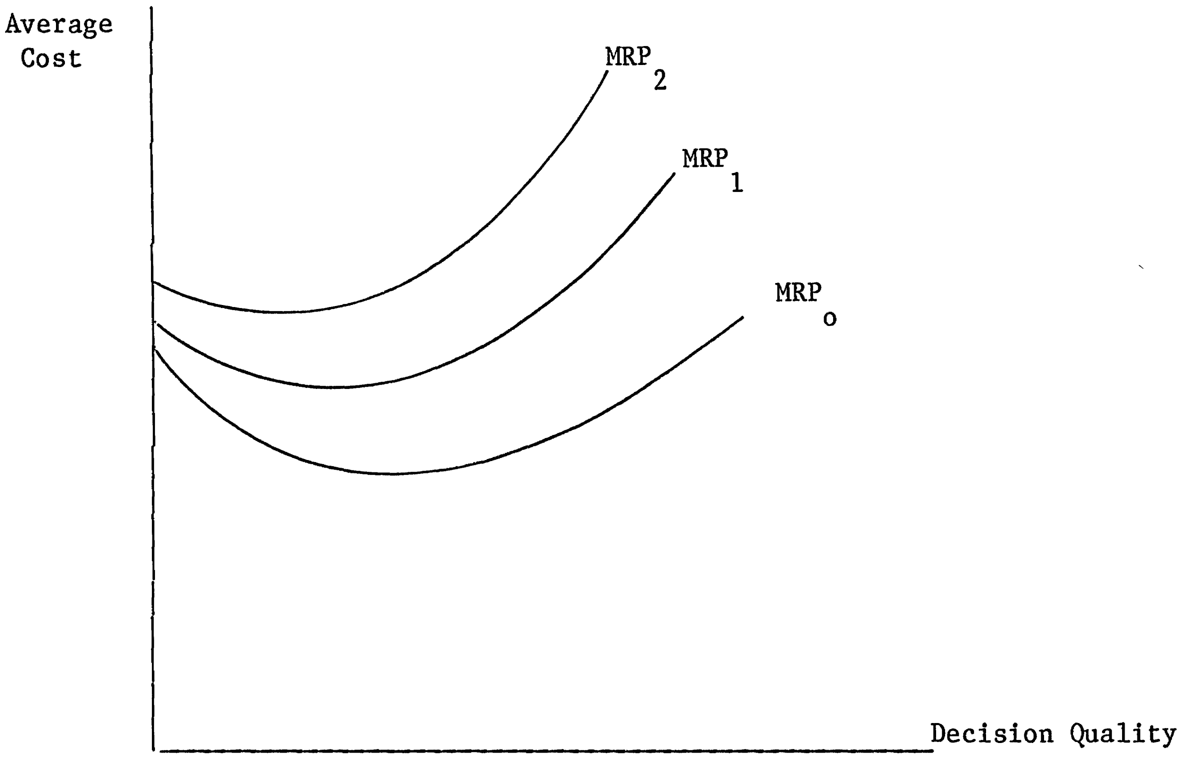


Figure 3. Effect of MRP Assumption Violations

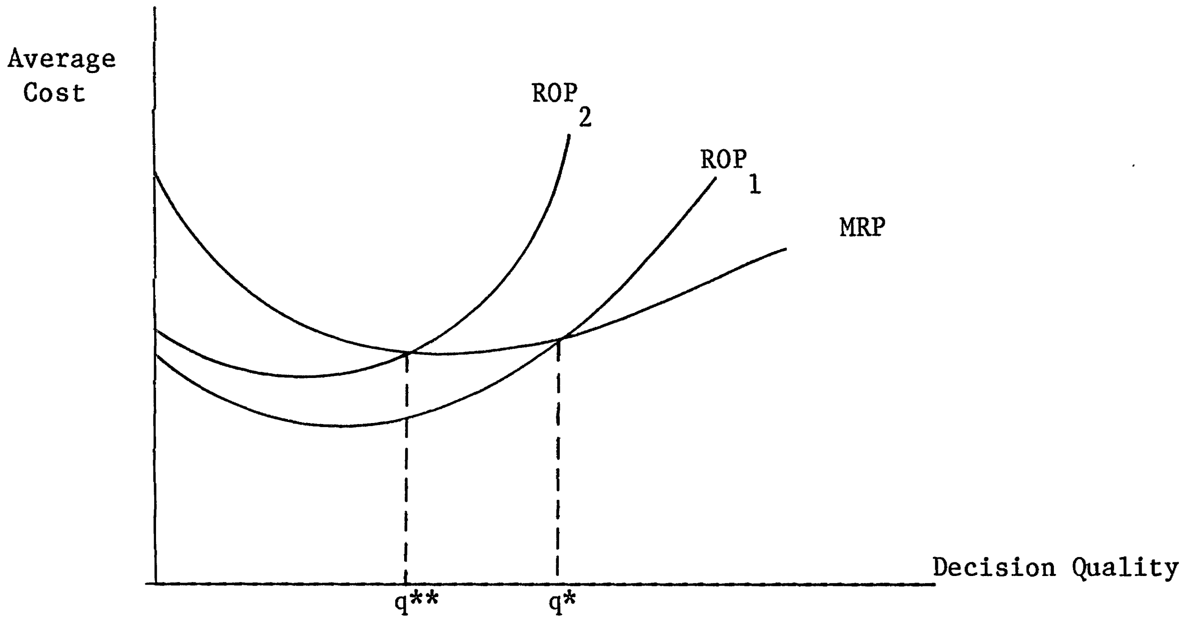


Figure 4. Assumption Violations and Critical Quality

production plans (e.g., daily regeneration instead of weekly). The cost associated with increased resources used for replanning purposes is then depicted by an upward shift in the long run average cost curve.

Environmental conflict with reorder point assumptions is posited to have a similar effect, shifting the reorder point long run average cost curve upward with each reorder point assumption violated.

The posited effect of cost curve changes upon MRP usage is illustrated in Figure 4. Here, as more reorder point (ROP) assumptions are violated (moving from $ROP_1$ to $ROP_2$), the critical level of quality decreases ($q^*$ to $q^{**}$), increasing the probability of MRP usage (that is, increasing the output range where MRP is appropriate.) Thus, increased reorder point assumption violations lead to higher reorder point long run average costs, which increase the probability of MRP usage. Following this logic, it is evident that MRP assumption violations lead to higher MRP costs, which reduce the probability of MRP usage.

MRP implementation costs reflect the effort required to set up an MRP system. This typically includes the computerization of manual files, production routing, etc., in addition to substantial organizational and procedural changes (these issues are discussed later). Similarly, reorder point implementation costs reflect the effort required to set up a reorder point system. This effort is typically significantly less than that required for MRP, and may involve relatively minor procedural changes (e.g., to implement a "two bin" system).

Since greater decision quality level requirements increase the probability of exceeding the critical quality, increased decision quality requirements positively influence expected MRP usage. Factors affecting decision quality requirements are discussed next.

The MRP usage model posits that increased firm production volume is associated with increased decision quality. This results from an assumption of efficient firm production, with all productive inputs (PIM decision quality, inventory, physical capacity, and non-management labor) being utilized to the point where their marginal cost - marginal product ratios are equal. Then increased firm production implies increases in all productive inputs, including PIM decision quality.[4,5]

The next factor shown to affect decision quality requirements is relative PIM decision productivity.[6] For a given firm production level, changing the productivity of an input should affect the quantity of that input used. The direction of that effect, however, is indeterminant. For, while increasing the relative productivity of an input results in a substitution of other inputs by the more productive input (a positive effect), the amount of all inputs required to produce the same output is decreased (a negative effect). Thus, though a relationship should exist between relative PIM decision productivity and the required decision quality level, the resulting direction of effect must be empirically determined.

Thus far, MRP costs have been illustrated as being initially higher than reorder point, and after a critical quality, lower than reorder point. This is due to the higher fixed costs associated with MRP's computerization requirement and fixed costs associated with MRP's organizational and procedural change requirements.[7] There are other possibilities, however, in which the cost curves cross more than once. Problems occur in these instances because linear predictions of MRP usage based upon decision quality level cannot be made. Though cost curves with multiple crossings confound the MRP usage model with respect to decision quality level requirements, model aspects dealing with assumption violation are not affected. Increased reorder point assumption violation should still lead to a greater probability of MRP usage, while increased MRP assumption violation should decrease expected MRP usage. These relationships hold because the range of decision quality levels in which MRP is appropriate still increase (decrease) with increased reorder point (MRP) assumption violations. Whether cost curve behavior is traditional, or involves multiple crossings is left to empiricial verification in this MRP context.

## 5. MODEL FOUNDATION SUMMARY

This section serves to draw together model concepts which are used in subsequent discussions.

Due to its neoclassical microeconomic foundation, the MRP usage model is based upon the following management philosophy: for a specific manufacturing context, and for a specific level of decision quality, the least cost decision making approach is chosen by the firm. The link between manufacturing contexts and decision making costs is achieved in the model through an evaluation of decision making approach assumption violations. With the MRP approach, contexts violating MRP assumptions result in higher decision making costs. With the reorder point approach, contexts violating reorder point assumptions result in higher decision making costs. Thus, in contexts violating MRP (reorder point) assumptions, the MRP approach is less (more) likely to be used.

The link between decision quality and decision making costs is analagous to the link between car production volume and costs of that production. Thus, given MRP and reorder point decision making long run average cost curves, the long run average cost associated with each decision making approach can be determined for any decision quality level. This enables a choice of the least cost approach for a specific decision quality. With the traditionally shaped cost curves described earlier, there is an intersection such that lower decision quality levels imply use of the reorder point approach, while higher decision quality levels imply use of the MRP approach.

Decision quality requirements are not treated as given in the model. Rather, these requirements are affected by firm production volume. Since, with efficient production, increases in firm production volume imply greater use of all inputs, firm production volume is expected to directly affect decision quality needs. Increases in decision quality requirements, in turn, increase the likelihood of exceeding the long run average cost curve intersection point; this results in a higher probability of MRP approach use. Another factor affecting decision quality requirements is the productivity of PIM decisions relative to the productivity of other firm production inputs, such as inventory and physical capacity. However, the direction of effect is uncertain. Higher relative PIM decision productivity implies that management should substitute decision quality for inventory and physical capacity (a positive effect), while increased productivity also implies a reduction of all firm production inputs to maintain a given firm production volume (a negative effect).

## 6. MRP USAGE MODEL

MRP usage has thus far been described as a function of:

- Environmental conflict with MRP assumptions
- Minimum MRP implementation costs
- Environmental conflict with reorder point assumptions
- Minimum reorder point implementation costs
- Firm production volume
- Relative productivity of PIM decisions.

As summarized in Figure 5, this section draws upon earlier discussions, to provide a more explicit formulation of the MRP usage model.

Environmental conflict with MRP assumptions is captured in the model through the use of a variable set $A^M$, representing the degree of violation of the following typical MRP assumptions [16] [18]:

$a_1^M$. Finished goods requirements are deterministic[8]

$a_2^M$. Manufacturing/purchase lead times are constant[9]

$a_3^M$. Costs are constant

$a_4^M$. Processes are independent: manufacturing of one component is not contingent upon the existence or progress of other production, except for the provision of input inventory items. For example, there are no requirements for the "mating" of processes, or sequential dependence of setups.

Similarly, environmental conflict with reorder point assumptions is captured in the model through the use of a variable set $A^r$, representing the degree of violation of the following typical reorder point assumptions:

$$\text{MRP Usage} = f(a_1^M, \ldots, a_4^M, a_1^r, \ldots, a_4^r, C_M, C_r, V, P)$$

where:

$a_i^M$ = Degree of violation of MRP assumption i.

$a_j^r$ = Degree of violation of reorder point assumption j.

$C_M$ = Minimum MRP implementation cost.

$C_r$ = Minimum reorder point implementation cost.

$V$ = Firm production volume.

$P$ = Relative productivity of PIM decisions.

Figure 5. MRP Usage Model Notation

$a_1^r$. Average inventory item usage is continuous and constant over time, with (random) deviations from the average described by a constant distribution [7, p. 171].

$a_2^r$. Manufacturing/purchasing lead times are either constant or can be described by a constant mean and standard deviation [7, p. 172].

$a_3^r$. Costs are constant [20].

$a_4^r$. Inventory items are independent: the demand or replenishment of one does not affect that of another [6, p. 249]. Thus, only single echelon (hierarchic level) inventory problems are addressed [20].

Expectations concerning the effect of these two assumption violation sets ($A^M$ and $A^r$) upon MRP use are as follows. As the number of violated MRP assumptions increase, and as the degree of MRP assumption violation increases, MRP use is expected to decrease. As described earlier, this results from an upward shift in the MRP long run average cost curve associated with these assumption violations. Similarly, as the number of violated reorder point assumptions increase, and as the degree of reorder point assumption violation increases, MRP use is expected to increase. This results from an upward shift in the reorder point long run average cost curve associated with reorder point assumption violation.

<u>MRP implementation cost</u> ($C_M$) represents fixed set up costs associated with the installation of an MRP system. These costs reflect the needs for computerization as well as organization and procedural changes. An increase in $C_M$ causes an upward shift of the MRP long run average cost curve and thus is expected to have a negative influence upon MRP usage.

Reorder point implementation cost ($C_r$) represents fixed set up costs associated with the installation of a reorder point system. A reorder point system does not necessarily require computerization, nor does it require much organization or procedural change. An increase in $C_r$ results in an upward shift of the reorder point long run average cost curve, and thus is expected to have a positive influence upon MRP usage.

Firm production volume (V) represents the quantity of finished goods produced per year. Given cost minimizing behavior, increases in firm production volume imply increases in the required amount of decision quality. Since increased decision quality requirements are posited to result in increased MRP usage, firm production volume is expected to have a positive influence upon MRP usage. This expectation assumes traditional long run average cost curve relationships.

As with firm production volume, relative PIM decision productivity (P) is linked to MRP usage through impacts upon required decision quality, and assumes traditional long run average cost curve relationships. If a PIM productivity change increases (decreases) required decision quality, then a positive (negative) influence upon MRP use is expected. However, as described earlier, the effect of PIM decision productivity changes upon required decision quality cannot be determined a priori. Thus expectations surrounding the impact of P upon MRP usage are indeterminate.

## 7. MRP USAGE MODEL ESTIMATION PROCESS

As a first step in developing a predictive model of MRP employment, model parameters can be estimated based upon actual MRP usage by firms. The actual model used in this study resulted from the theoretical model presented above, adapted according to data availability. Since a survey approach was used, variables such as the relative productivity of PIM decisions were considered too difficult for respondents to estimate. Thus, surrogate measures were developed, resulting in an altered model.

The survey, described below, provides the context for surrogate measure choice. This is followed by descriptions of the altered model and its associated measures (summarized in Figure 6).

## 7.1 SURVEY

Data required for model estimation were gathered via telephone interviews of production and inventory control managers and staff. The American Production and Inventory Control Society (APICS) provided a random sample of its membership across the United States.[10]

This telephone interview approach was chosen to reduce confusion over terminology and to encourage a high response rate. The response rate was 97% of contacted applicable members. Of the 100 member random sample, 36 were eliminated through logistical problems or failing to meet survey requirements. Of the remaining members, only 2 refused to answer the survey. Hence, the results are based upon APICS members working in a random sample of 62 manufacturing facilities in the United States.

## 7.2 SURROGATE MEASURES BASED UPON MARKETING STRATEGY AND MANUFACTURING METHOD[11]

Though questions concerning firm production volume can be directly asked, it would be difficult to have APICS members estimate the degree of violation of the following assumptions:

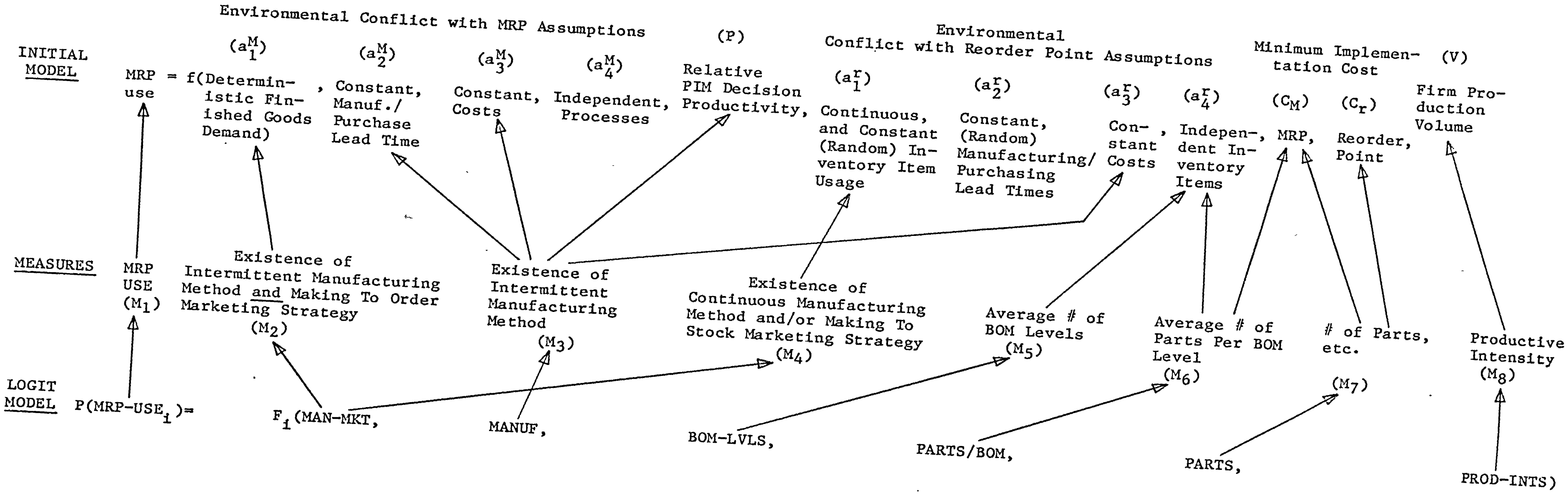


Figure 6. MRP Usage Model, Its Measures, and Resulting Logit Model

MRP Assumptions

- Deterministic finished goods requirements ($a_1^M$)

- Constant manufacturing/purchase lead times ($a_2^M$)

- Constant costs ($a_3^M$)

- Independent processes ($a_4^M$)

Reorder Point Assumptions

- Continuous and constant (random) inventory item usage ($a_1^r$)

- Constant (random) manufacturing/purchasing lead times ($a_2^r$)

- Constant costs ($a_3^r$)

In addition, relative PIM decision productivity (P) would be difficult to determine during an interview. Surrogate measures were thus developed to depict these eight initial model variables. An overriding concern in the choice of these measures was that they be understood and readily determined by interviewees. Thus, the production and inventory control literature was surveyed to identify commonly understood concepts and associated jargon. The following discussion describes the surrogate measures and their derivations.

Two manufacturing concepts which tend to be basic to most production and inventory control discussions concern manufacturing method and marketing strategy (e.g., [7, p. 5]). Because of the common understanding of these manufacturing method and marketing strategy concepts, and their relative ease in application to various manufacturing contexts, they are used as surrogate measures. The use of this manufacturing method and marketing strategy framework as a surrogate measure takes the following form. First, links between manufacturing contexts described by the framework and violations of the seven MRP and reorder point assumptions are identified. A context described by a specific manufacturing method and marketing strategy which is found to be consistantly associated with an assumption violation can then be used to "measure" the existence of that assumption violation.[12]

A review of the production and inventory management literature revealed the following links between the manufacturing method-marketing strategy framework and MRP use model variables (see Figure 6).

- The MRP deterministic finished goods demand assumption ($a^{M}_{1}$) is violated in contexts characterized as intermittent manufacturing method and making to order marketing strategy ($M_2$). Thus, a context of this nature is expected to be associated with reduced MRP use.

- The MRP assumptions of constant manufacturing/purchase lead times ($a^{M}_{2}$) and constant costs ($a^{M}_{3}$) are violated in contexts characterized as intermittent manufacturing method, regardless of the marketing strategy ($M_3$). In addition, this context violates the reorder point constant cost assumption ($a^{r}_{3}$). Since the effect upon MRP use associated with MRP assumption violation contradicts that associated with reorder point assumption violation, expectations surrounding the impact of these contexts upon MRP use are indeterminant. This indeterminacy is compounded because PIM decisions were found to be relatively productive in intermittent manufacturing contexts. As described earlier, the effect of relative PIM decision productivity upon MRP use is itself indeterminate.

- The reorder point assumption of continuous and constant (random) inventory item usage ($a^{r}_{1}$) is violated in contexts characterized as continuous manufacturing method and/or making to stock marketing strategy ($M_4$). Thus, contexts of this nature are expected to be associated with increased MRP use.

These three surrogates ($M_2$, $M_3$, and $M_4$) are included in the altered MRP use model as dichotomous measures. Each measure reflects the existence or non-existence of the associated manufacturing context.

## 7.3 SURROGATE MEASURES FOR MRP AND REORDER POINT COSTS

Two additional initial model variables, MRP implementation cost ($C_M$) and reorder point implementation cost ($C_r$), would also be difficult for APICS members to estimate. Thus, as described below, surrogate measures were developed to capture the influence of these costs.

MRP implementation cost was described earlier as reflecting the requirements of computerization and procedural and organizational changes. A major factor underlying these requirements is manufacturing complexity: as the number of parts, components, and raw materials and their interrelationships increase, the MRP "model" must become more complex and more accurate to adequately depict production. Two surrogate measures are thus introduced to represent this complexity: number of parts, etc. ($M_7$), and average number of parts per Bill of Material (BOM) level ($M_6$). $M_7$ consists of the number of different kinds of parts, components, and raw materials used to produce all of the firm's products. $M_6$ reflects the decomposition rate of parts, components, and raw materials per BOM level for the typical product of a firm, and is used to depict the interrelationship complexity among the various parts, etc. Both $M_7$ and the components of $M_6$ are taken directly from the survey.

Reorder point implementation cost was described earlier as largely reflecting required procedural changes. An important factor affecting the degree of change required is the number of different parts, components, and raw materials used in production; for each part, etc. may require a different reorder point algorithm/procedure. Thus, number of parts, etc. ($M_7$), as described above, is used here as a surrogate for reorder point implementation cost. Note that because the reorder point approach typically ignores interaction among the various parts, etc., average number of parts per BOM level ($M_6$) is not used as a surrogate here.

Expectations concerning the effect of number of parts, etc. ($M_7$) upon MRP use are confounded due its impact upon both MRP ($C_M$) and reorder point ($C_r$) implementation costs. Due to its impact upon MRP implementation cost, average number of parts per BOM level ($M_6$) is expected to negatively influence MRP use.

8. DIRECT MEASURES

This section describes the remaining measures used for estimating the MRP use model.

The MRP usage model's dependent variable measure - MRP use ($M_1$) - was determined by asking for a description of MRP in the respondent's facility, in terms of the following classification scheme:[13]

- Class A: Closed-loop system used for both priority planning and capacity planning. The master production schedule is leveled and used by top management to run the business. Most deliveries are on time, inventory is under good control, and little or no expediting is done.

- Class B: Closed-loop system with capabilities for both priority planning and capacity planning. However, the master production schedule is somewhat inflated. Top management does not give full support. Some inventory reductions have been obtained, but capacity is sometimes exceeded and some expediting is needed.

- Class C: Order launching system with priority planning is done informally with a probable inflated Master Production Schedule. Expediting is used to control the flow of work. A modest reduction in inventory has been achieved.

- Class D: The MRP system exists mainly in data processing. Many records are inaccurate. The informal system is largely used to run the company. Little benefit is obtained from the MRP system.

- None: MRP not used.

Though MRP usage has been classified by the survey into five categories, the logit model reduces this classification to three: Successful MRP, Useful MRP, and No MRP. Successful MRP includes A and B use, and depicts a closed loop system with much of the expected production and inventory gains. This collapsing of the A and B categories was due to the relatively few firms classified as A or B users, and is in accord with MRP literature definitions of successful MRP systems. Useful MRP consists of C use, and depicts an MRP system which has been implemented and provides some benefit. No MRP includes D use, since a D MRP system has not resulted in any benefit.

Average number of BOM levels ($M_5$) represents product structure complexity in terms of the typical depth to bills of material used in the manufacture of finished goods, and is taken directly from the survey. Since larger values violate the reorder point independent inventory item assumption ($a_4^r$), average number of BOM levels is expected to positively impact MRP use.

Average number of parts per BOM level ($M_6$) represents product structure complexity in terms of the average decomposition rate of parts, components, etc. per BOM level. In addition to directly violating the reorder point assumption of independent inventory items ($a_4^r$), average number of parts per BOM level acts as a surrogate for one component of minimum MRP implementation cost ($C_M$). Its expected impact upon MRP use is confounded by this dual role.

Productive intensity ($M_8$) represents a firm's production volume (V), which is posited to be directly related to the required amount of decision quality. When viewing a single firm, increased production volume is expected to result in increased decision quality. However, two firms with the same production volume may have different decision quality needs. This may be due to different levels of complexity involved in production, the more complex operation requiring more decision quality. Productive intensity thus combines both production volume and complexity to enable inter-firm comparisons. Production volume is taken directly from the survey, and is multiplied by the number of parts, components, etc. per end item. Since increased decision quality needs are posited to lead to increased MRP use productive intensity is expected to be positively related to MRP use.

## 9. MRP USAGE MODEL: LOGIT FORM

This section presents the modified MRP use model which incorporates the above measures, and thus allows estimation with telephone survey data. Because of the use of a dichotomous dependent variable measures (discussed below), and the presence of dummy independent variable measures, a logistic regression model (logit) is appropriate [2]. The logit model employed is illustrated in Figure 7. Relationships between the logit model and its measures are summarized in Figure 6. The following discussions provide details of this logit model.

$$P(\text{MRP-USE}_i) = F_i(K + \alpha_1 \text{MAN-MKT} + \alpha_2 \text{ MANUF} + \alpha_3 \text{ BOM-LVL}$$
$$+ \alpha_4 \text{ PARTS/BOM} + \alpha_5 \text{ PARTS} + \alpha_6 \text{ PROD-INTS})$$

where:

| | | |
|---|---|---|
| $P(\text{MRP-USE}_i)$ | = | Probability of MRP use ($M_1$). $P(\text{MRP-USE}_1)$ is the probability of Useful rather than No MRP system. $P(\text{MRP-USE}_2)$ is the probability of Successful rather than Useful MRP system. $P(\text{MRP-USE}_3)$ is the probability of Useful or Successful rather than No MRP system. |
| MAN-MKT | = | Intermittent manufacturing method <u>and</u> making to order marketing strategy rather than any of the other three manufacturing method-marketing strategy combinations ($M_2$ and $M_4$). |
| MANUF | = | Intermittent manufacturing method rather than continuous manufacturing method ($M_3$). |
| BOM-LVLS | = | Average number of BOM levels in production ($M_5$). |
| PARTS/BOM | = | Average number of parts, etc. per BOM level ($M_6$). |
| PARTS | = | Total number of different kinds of parts, etc. ($M_7$). |
| PROD-INTS | = | Productive intensity ($M_8$): total production volume in one year times the total number of different parts per end item. |

Figure 7. Logit MRP Use Model

Figure 7 depicts three different logit models ($F_i$, for i=1,2,3) based upon the three different MRP use categories. $F_1$ estimates the probability, P(MRP-USE$_1$), that certain environmental factors lead to the existence of Useful rather than No MRP systems. $F_2$ estimates the probability, P(MRP-USE$_2$), that certain environmental factors lead to the existence of Successful rather than Useful MRP systems. $F_3$ estimates the probability, P(MRP-USE$_3$), that certain environmental factors lead to the existence of successful MRP use (i.e., Useful or Successful) rather than No MRP use.

Coding of the dependent variable for each model is as follows. MRP-USE$_1$ is coded 1 for Useful MRP systems, 0 for No MRP systems, and is not included for Successful MRP systems. MRP-USE$_2$ is coded 1 for Successful MRP systems, 0 for Useful MRP systems, and is not included for No MRP systems. MRP-USE$_3$ is coded 1 for Useful or Successful MRP systems, and 0 for No MRP systems.

Since the two surrogate measures involving both manufacturing method and marketing strategy ($M_2$ and $M_4$) are perfectly negatively correlated [9, Chapter 7], a single logit measure combining these two measures was created. This logit measure, MAN-MKT, is coded zero for intermittent manufacturing method <u>and</u> make to order marketing strategy, and is coded one for the three other combinations. With this coding, MAN-MKT is expected to be positively related to P(MRP-USE$_i$).

MANUF represents the existence of an intermittent manufacturing method ($M_3$), and is coded zero for continuous manufacturing and one for intermittent manufacturing. Due to the multiple implications of $M_3$ upon the MRP use model, expectations of MANUF's impact upon P(MRP-USE$_i$) are indeterminate.

BOM-LVLS represents the average number of BOM levels in production ($M_5$). BOM-LVLS is a continuous measure, and is taken directly from the survey. It is expected to be positively related to P(MRP-USE$_i$).

PARTS/BOM depicts the average number of different parts, components, and raw materials used per BOM level ($M_6$). Values for PARTS/BOM were determined by:

parts/(#-end-items x #-BOM-levels)

where parts is the number of different parts, components, and raw materials used in production, #-end-items is the number of end items produced per year, and #-BOM-levels is the average number of BOM levels used in production. Actual PARTS/BOM values used are zero or one, depending upon whether the average number of parts, etc. per BOM level is less than or greater than its median. The use of a dichotomous measure rather than actual values resulted from problems in defining end items. For example should a computer manufacturer which produces a single type of hardware, but provides ten software combinations be categorized as having one or ten items? These problems lead to a false measurement precision. A dichotomous measure is thus employed to reduce this precision to a level commensurate with the measurement error.

PARTS represents the number of different kinds of parts, components, and raw material used in production ($M_7$). PARTS is a continuous measure, taken directly from the survey. Because of its dual role, representing both MRP and reorder point minimum implementation costs, expectations of PARTS effect upon P(MRP-USE$_i$) are indeterminate.

PROD-INTS depicts the productive intensity of a firm ($M_8$), and is derived from the total production volume in one year times the average number of different kinds of parts, components, and raw materials used per end item. As employed here, PROD-INTS is a dichotomous measure, coded zero for values less than its median, and one for greater values. This coding scheme is used to bring the measurement precision in line with the measurement error associated with production volume estimates. Problems were encountered because volume estimates were provided in different metrics (items, feet, cases, etc.). PROD-INTS is expected to be positively related to P(MRP-$USE_i$).

## 10. ESTIMATION RESULTS

This section contains results of logistical regressions run on the three MRP use functions. A results summary is presented in Figure 8. Parameter estimates of the two significant models (MRP-$USE_1$ and MRP-$USE_3$) are in accord with expectations. Note that MRP-$USE_3$, which includes the complete sample, has a sample size of 60. This is because two of the respondents could not provide production volume data.

## 11. DISCUSSION OF RESULTS

This section is divided into two parts. First, estimated models are examined to gain descriptive insight into MRP usage. Second, the models' predictive implications are explored.

### 11.1 DESCRIPTIVE INSIGHT

The lack of MRP-$USE_2$ significance indicates that environmental conditions alone could not distinguish between contexts which are more conducive to successful, rather than useful, MRP installation. Thus, the "failure to move" from a Class C MRP user to a Class A or B user may be the result of

| Estimated Function | $R^2$ | Sig | N |
|---|---|---|---|
| $P(\text{MRP-USE}_1)$: Useful vs. No MRP = −1.36 (.28) + .34 MAN-MKT (.74) − 1.26 MANUF (.20) + .19 BOM-LVLS (.34) −2.25 PARTS/BOM (.01) + .50 PROD-INTS (.62) | .19 | .03 | 46 |
| $P(\text{MRP-USE}_2)$: Successful vs. Useful MRP = .70 (.66) − .17 MAN-MKT (.88) − .33 MANUF (.74) + .07 BOM-LVLS (.68) −.14 PARTS/BOM (.86) + .32 PROD-INTS (.78) | .01 | .99 | 41 |
| $P(\text{MRP-USE}_3)$: Useful/Successful vs. No MRP = −1.91 (.20) + .36 MAN-MKT (.70) − 1.66 MANUF (.08) + .25 BOM-LVLS (.21) −2.63 PARTS/BOM (.00) + .57 PROD-INTS (.54) | .23 | .00 | 60 |

Note:
1. Significance of t statistics for estimated parameters are indicated parenthetically.
2. $R^2$ is the logit analogue: 1- log likelihood at convergence ÷ log likelihood with independent variables equal to zero.
3. Initial estimations included PARTS. However, the coefficient of PARTS (=−.0000087) indicated its immateriality. This conclusion is strengthened by the fact that a change from its 25th percentile value (2,300) to its 50th percentile value (5,200) leads to less than a 1% effect upon $P(\text{MRP-USE}_3)$. Thus, PARTS was excluded, and the functions reestimated as shown above.

Figure 8 Logit MRP Use Model Estimates

more implementation-specific issues, such as the lack of management understanding and commitment, resistance to change, etc.

Significance of the two remaining models, MRP-USE$_1$ and MRP-USE$_3$, imply that environmental conditions can be identified which are not consistent with any type of MRP use. The remainder of this section examines MRP-USE$_3$. This model is chosen, rather than MRP-USE$_1$, because it applies to MRP use in general.[14]

Unlike OLS regression, logistic regression coefficients are not directly interpretable. Though positive coefficients result in positive influences upon the dependent variable, effects are non-linear, and contingent upon other independent variable values. Discussions below thus explore the impact of selected measures and components of measures upon the probability of MRP use.[15] These measures and components were chosen to provide a framework which can be easily applied to describe various manufacturing contexts. This framework allows such descriptions in terms of:

- Marketing strategy (make-to-order or make-to-stock)
- Manufacturing method (continuous or intermittent)
- Average number of different parts, components, and raw materials used per finished good
- Average number of BOM levels
- Finished goods production volume per year

The linkage between this framework and the logit model is as follows. Marketing strategy impacts the probability of MRP use through MAN-MKT. Manufacturing method impacts the probability of MRP use through MAN-MKT and MANUF. Average number of different parts, etc. used per finished good impacts the probability of MRP use through PARTS/BOM and PROD-INTS. Average number of BOM levels impacts the probability of MRP use through BOM-LVLS and PARTS/BOM. Finished goods production volume per year impacts the probability of MRP use through PROD-INTS.

Figure 9 provides MRP use probabilities associated with environmental descriptions allowed by the framework. For simplicity, all measures and components are dichotomous. Marketing strategy and manufacturing method are coded zero or one in accord with earlier descriptions. Average number of different parts, etc. used per finished good and finished goods production volume per year are coded zero or one, depending upon whether they are below or above their medians (24 and 67,000, respectively). Because it is used in the model as a continuous measure, the average number of BOM levels is represented by its 25th percentile value (3.3) or its 75th percentile value (5.5) for levels below or above its median (4).

As an example of the use of Figure 9, consider the following characterization of a responding firm that produces electro-mechanical items for the aero-space industry:

- Marketing strategy - estimated that 80% of production was to order; classified as to order
- Manufacturing method - characterized as job shop; classified as intermittent
- Average number of different parts, etc. per finished good - estimated at 250; classified as high
- Average number of BOM levels - estimated at 5; classified as high
- Finished goods production volume per year - estimated at 1,600; classified as low.

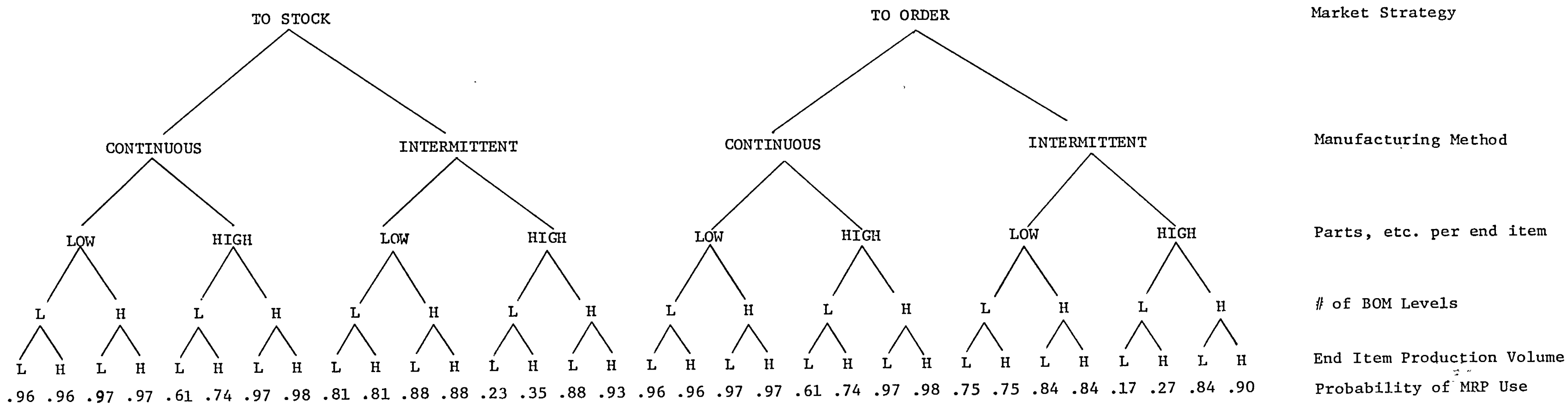


Figure 9 Manufacturing Environmental Conditions
With Associated MRP Use Probabilities

As illustrated in Figure 9, there is an 84% likelihood that MRP will be used in a firm with these characteristics. In fact, the firm does use MRP.

In general, a firm's manufacturing method and product structure complexity seem to have the greatest impact upon MRP use. Continuous manufacturing with relatively few parts, etc. per end item provides for better than 95% probability of MRP use. The least probability of MRP use (ranging from .17 to .35) is associated with intermittent manufacturing, relatively many parts, etc. per end item, and relatively few BOM levels.

## 11.2 PREDICTIVE IMPLICATIONS

The MRP use descriptions provided above enable predictions of the incidence of MRP use in specific environments. However, it would be of great interest to predict the appropriateness of MRP in those environments. This would allow more informed choices regarding MRP implementation. Because of the microeconomic theoretical foundation employed, predictive clues regarding MRP appropriateness can be ascertained. It is postulated that firms will use MRP except when the environment makes it too costly. This implies that environments leading to less MRP use have higher costs associated with MRP implementation. MRP use probabilities, can then be interpreted as probabilities that MRP is the least cost alternative and thus, probabilities that MRP is the appropriate PIM decision-making approach.

Earlier descriptive discussions regarding the likelihood of MRP use can now be used to identify environments in which MRP is appropriate. In summary, Figure 9 illustrates the fact that firms involved in intermittent (or job shop) manufacturing with a relatively complex product structure (in terms of parts, components, and raw materials per BOM level) seem to be the least appropriate for MRP implementation. The most appropriate environment is that with continuous (or assembly line) manufacturing and a relatively simple product structure. Interestingly, this is counter to that historically suggested for MRP implementation (e.g., [16, p. 42]).

Predictions discriminating between Useful MRP installation (class C user) and Successful MRP installations (class A or B user) could not be made based upon the environmental factors used in this study. This implies that firm-specific factors play a larger role in determining the extent of MRP involvement within an appropriate environment.

## 12. CONCLUSION

Building upon the DPS foundation, a model was developed which characterizes the use of MRP within various environments. Motivating this model was the persistent claim that MRP's full potential was not being exploited; though many firms had tried MRP, many of the expected benefits had not been obtained. It was hypothesized here that one reason for MRP failure was its implementation in inappropriate environments. Thus, a model of MRP use was developed which focused upon the cost of producing decisions. It was found that there are indeed contexts less suited to MRP implementation. Interestingly, these contexts are among those historically suggested for MRP implementation: intermittent manufacturing with relatively complex product structures. In addition, environmental conditions were not able to differentiate between A, B, and C classes of MRP use. This indicates that, given a suitable environment, firm-specific factors such as top management support, user education, etc. may play a more important role in determining the appropriateness of MRP use.

In this study, external validity to United States' manufacturing firms is relatively high. Data were gathered from a random sample of production managers and staff, based upon the American Production and Inventory Control Society membership. Thus, selection bias exists only to the extent that the society's members (numbering over 50 thousand) do not reflect manufacturing in the United States. In addition, the very high response rate (97%) reduces selection bias concerns even further.

In conclusion, this paper has provided one of the first empirically-based models of MRP usage and applicability. The study results have interesting implications for both production managers and researchers. In addition, the modelling approach may provide a useful foundation for other studies of management information systems or decision support systems.

## FOOTNOTES

1 MRP will also refer here to Manufacturing Resource Planning.

2 MRP and reorder point methods represent two basic approaches for PIM [18, p. 13]. Note that a new Japanese approach to repetitive manufacturing PIM, called KANBAN or Just-In-Time, is not addressed here. Though there are currently few KANBAN - oriented manufacturing in the United States [14, p. 31], it may provide important opportunities for some U.S. firms.

3 As described below this trade off based upon output level is contingent upon other contextual factors.

4 This assumes a regular firm production function which, for example, does not have negative cross marginal products of large absolute value [19, p. 109].

5 Note that the long run average cost of PIM decisions should play a part in determining the appropriate level of firm production. For it is the cost of the firm's product along with its potential revenue which identifies profit maximizing production. However, this link from PIM cost to firm production level is ignored here for the following reasons:

- Profit maximization is a stronger and more tenuous assumption than the efficient production assumptions thus far imposed. [11, p. 48].
- Changes within the normal range of PIM costs are probably insignificant in determining the profit maximizing level of of production. For example, a recent survey by Anderson et al. [1] indicated that the total cost of MRP installation averages less than 3% of a firm's gross revenue for one year.

6 Relative PIM decision productivity can be thought of in terms of firm production output elasticities. Relative PIM decision productivity could be measured as its firm production output elasticity divided by the sum of the other firm production output elasticities. (Here, the other output elasticities are those for inventory and physical capacity.) This measure is particularly convenient if the firm production function is Cobb-Douglas, since output elasticities are constant. Note: PIM decision productivity refers here to the productivity of decisions in terms of firm production, not productivity in creating decisions.

7 Due to the amount of data manipulation, some level of computerization is necessary for MRP use [13]. In addition to initial computer hardware and software costs, significant setup costs are associated with reoraniza-tion to achieve the required level of accuracy and detail for MRP. For example, bills of material must be made current, accurate, and explicit; procedures must be instituted to enable very accurate tracking of inventories (raw and work-in-process); engineering bills and production bills must be combined into a single scheme; more accurate estimates of production resources and timing must be made; etc.

[8,9] Though the use of safety stocks to account for supply or demand uncertainty is promoted as taking random variations into account (e.g., [22]) they are actually part of the inventory level - PIM trade off. That is, one can substitute less PIM decision quality for higher inventory levels and maintain the same firm production level [9]. Safety lead time also results in higher inventory.

[10] The total membership exceeds 50 thousand.

[11] See [9] for details of this section.

[12] Note that this scheme results in a dichotomous measure, which indicates whether an assumption violation is significant. Here, significance exists to the extent that the violation of an MRP (reorder point) assumption significantly degrades the MRP (reorder point) model's performance.

[13] This classification scheme was developed by Anderson, et al. [1], based upon Wight [24].

[14] Note that in this and subsequent sections, "insignificant" coefficient values are used in descriptive and predictive discussions. Though "not significant," these coefficients represent the best estimate of actual model values.

[15] Probabilities of MRP use result from logistical regressions.

## REFERENCES

[1] Anderson, John C., Schroeder, Roger G., Tupy, Sharon E., and White, Edna M. Material requirements planning: a study of implementation and practice, American Production and Inventory Control Society, Falls Church, Virginia, 1981.

[2] Ball, Clifford A. and Tschoegl, Adrian E. The decision to establish a foreign bank branch or subsidiary: an application of binary classification procedures. Journal of Financial and Quantitative Analysis 17, 3 (September 1982), 411-424.

[3] Belt, Bill. Men, spindles, and material requirements planning: enhancing implementation. Production and Inventory Management, First quarter 1979, 54-65.

[4] Blumberg, Donald F. Factors affecting the design of a successful MRP system, Production and Inventory Management, Fourth quarter 1980, 50-61.

[5] Boxx, Douglas B. MRP--selling a dead horse (or how to convince management to invest in MRP). Production and Inventory Management, Second quarter 1979, 49-62.

[6] Buffa, Elwood S. Modern Production/Operations Management, Sixth edition, John Wiley & Sons, 1980.

[7] Buffa, Elwood S. and Miller, Jeffrey G. Production-Inventory Systems Planning and Control, Third edition, Richard D. Irwin, 1979.

[8] Cooper, Randolph B. and Swanson, E. Burton. Management information requirements: the state of the art. Data Base 11, 2 (1979), 5-16.

[9] Cooper, Randolph B. Decision Production: A Microeconomic view of Decision Making with Implications for Management Information Systems. Unpublished Ph.D. dissertation, UCLA, 1983.

[10] Cooper, Randolph B. A step toward a theory of managerial information requirements. Proceedings of the Fourth International Conference On Information Systems, December 1983.

[11] Ferguson, C. E. The neoclassical theory of production and distribution. Cambridge University Press, London, 1969.

[12] French, Robert L. Accurate work in process inventory--a critical MRP system requirement. Production and Inventory Management, First quarter 1980, 17-22.

[13] Gelders, Ludo F. and Van Wassenhove, Luk N. Production planning: a review. European Journal of Operations Research 7 (1981), 101-110.

[14] Hall, Robert W. Driving the productivity machine: production planning and control in Japan. American Production and Inventory Control Society, Falls Church, Virginia, 1981.

[15] New, Colin. Requirement Planning, John Wiley and Sons, New York, 1973.

[16] Olicky, Joseph. Material Requirements Planning, McGraw-Hill, New York, 1975.

[17] Plossl, George W. MRP yesterday, today, and tomorrow. Production and Inventory Management, Third quarter 1980, 1-9.

[18] Plossl, George W. Manufacturing Control, the Last Frontier for Profits, Reston Publishing Co., 1973.

[19] Silberberg, Eugene. The structure of economics: a mathematical analysis. McGraw-Hill, New York, New York, 1978.

[20] Silver, Edward A. Operations research in inventory management: a review and critique. Operations Research 29, 4 (July-August 1981), 628-645.

[21] White, Edna M. Implementing an MRP system using the lewin-schein theory of change. Production and Inventory Management, First quarter 1980, 1-12.

[22] Whybark, D. Clay and Williams, J. Gregg. Material requirements planning under uncertainty. Decision Sciences 7 (1976), 596-606.

[23] Wight, Oliver, W. Production and Inventory Management in the Computer Age, Cahners Books, Boston, Mass., 1974.

[24] Wight, Oliver, W. Time for the annual checkup. Newsletter, 1977.