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CONTENTS

LOT SIZING PROCEDURES FOR REQUIREMENTS PLANNING SYSTEMS: A FRAMEWORK FOR ANALYSIS

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ABSTRACT

Several procedures have been proposed for determining the lot size and timing of deliveries for manufactured components in requirements planning systems. These include the use of: Economic Order Quantities, Periodic Order Quantities, Part Period Balancing, and the Wagner-Whitin Algorithm. Yet, very little data has been prepared to guide the production manager in selecting a procedure. This paper presents a framework for comparing such procedures with respect to two criteria: inventory related costs, and computing time.

Requirements planning systems are receiving increased attention by production and purchasing managers as many firms turn to the computer for assistance in planning and controlling manufacturing operations [9,10]. These systems reduce a master schedule of finished products to a time phased schedule of requirements for intermediate assemblies and component parts. The resulting forecast of component requirements is critical in planning the lot size and timing of replenishment orders for both manufactured and purchased items. Since this task often involves processing large amounts of detailed information, as well as making a substantial number of routine decisions, it is a logical candidate for processing on the computer.

Computer based requirements planning systems frequently include a procedure for determining the lot size and timing of replenishment orders to meet the forecast requirements. Thus, one problem often encountered in designing such a system is that of selecting a procedure for making lot size decisions. Although a number of procedures have been proposed, ranging from the use of simple decision rules to extensive optimizing procedures, there is surprisingly little guidance for the manager in selecting a lot sizing procedure for his system. The problem in selecting a procedure is that reductions in inventory related costs can generally be achieved only by using increasingly complex procedures. Such procedures are less easily understood by operating personnel and require more computations in making lot size decisions.

This paper is the first of two papers which deal with a comparison of four prominently mentioned ordering procedures for requirements planning sys-

Week Number	1	2	3	4	5	6	7	8	9	10	11	12
Requirements	10	10	15	20	70	180	250	270	230	40	0	10

Ordering Cost: S = $300 per order

Inventory Carrying Cost: C_I = $2 per unit per week

Table 1—Example Problem: Weekly Requirements Schedule

tems: Economic Order Quantities, Periodic Order Quantities, Part Period Balancing, and the Wagner-Whitin Algorithm. In this paper we present a framework for comparing the performance of these procedures over a broad range of cost and demand data parameters. The second paper will report a simulation analysis in which the framework we propose has been used to evaluate the performance of the four ordering procedures discussed in this paper.

In the present discussion, we describe the ordering problem often encountered in a requirements planning system and present a performance comparison of the four lot sizing procedures mentioned above using a single example. Next, we describe the problems associated with making simple performance comparisons. Finally, we suggest a more general framework for comparing the performance of alternative lot sizing procedures and provide an illustration of its application.

The Ordering Problem

The ordering problem that we are concerned with is basically one of converting a forecast of component requirements into a series of replenishment orders. This involves determining how to group the time phased requirements data into a schedule of replenishment orders which minimizes the combined costs of placing orders and carrying inventory.[1] The example shown in Table 1 illustrates a typical requirements forecast that is considered in planning the lot size and timing of replenishment orders.[2]

Although this ordering problem occurs in a wide variety of manufacturing and purchasing situations, we shall only consider the problem in the context of a requirements planning system, i.e. when the demand forecast is derived by an explosion of finished product requirements. In this case, the schedule of weekly requirements for an individual component, like the one shown in this example, is derived by exploding the scheduled production for all higher level assemblies into the necessary component parts. The weekly requirement for each component is then obtained by accumulating its weekly usage in all higher level assemblies. Thus a forecast of component requirements, covering the next 12 weeks in this case, is prepared.[3]

Since computer time is an important factor in preparing a requirements schedule for individual components, requirements planning systems are often operated on a daily or weekly basis, i.e. batch processed. Because this mode of operation affects our view of the ordering problem, we shall state our assumptions before proceeding. First, since the component requirements are aggregated by time period for planning purposes, we assume that all of the requirements for each period must be available at the beginning of the period. Second, we assume that all of the requirements for a given period must be met and cannot be backordered. Third, since the system is operated on a periodic basis, the ordering decisions are assumed to occur at regular time intervals, e.g. daily or weekly. Fourth, the orders which are placed at the beginning of a period, are assumed to be available in time to meet the requirements for that period. This assumption of zero production lead time is not very restrictive, however, since once the ordering decisions are made, they can be offset to allow for the production lead time. Finally, we assume that the components are withdrawn from inventory at a uniform rate during each period. Therefore the average inventory level will be used in computing the inventory carrying costs.[4]

In the following sections we shall illustrate the results obtained by applying four different ordering procedures to the example shown in Table 1. Furthermore, this example will be used to illustrate the manner in which these procedures vary in their assumptions and the extent to which they utilize all of the available data in making lot size decisions.

Economic Order Quantities: The economic lot size formula is often used as a decision rule for placing orders in a requirements planning system because of its simplicity [8,10]. As we shall illustrate in the following example, however, the static EOQ model frequently must be modified in requirements planning system applications. It is important to recognize this fact because, in many cases, it prevents one from using the total cost expression for the static EOQ model in evaluating the inventory cost performance of this procedure.

The results obtained by ordering material in economic lot sizes for the

[1] In the case of a purchased part, the inventory related costs may also include quantity discount and transportation rate schedules [14].

[2] This example was obtained from an article by Kaimann [7]. The item value in this case is $520 per unit and the inventory carrying charge is 20 percent of the item value per year.

[3] In this paper we shall assume that the requirements forecast remains fixed and is not subject to forecast error. Since this assumption is unwarranted in a number of actual situations, the effect of forecast errors on the performance of the lot sizing techniques mentioned in this paper is an important problem for further research.

[4] An interesting comparison of these assumptions with those of the static Economic Order Quantity model is presented by Gorenstein [3].

Week Number	1	2	3	4	5	6	7	8	9	10	11	12
Requirements	10	10	15	20	70	180	250	270	230	40	0	10
Order Quantity	166					166	223	270	230	166		
Beginning Invt.	166	156	146	131	111	207	250	270	230	166	126	126
Ending Invt.	156	146	131	111	41	27	0	0	0	126	126	116

Ordering Cost: $1800

Inventory Carrying Cost: 3065

Total Cost: 4865

(Economic Lot Size = 166)

Table 2—Economic Order Quantity Example

example above are presented in Table 2.[5] In this example the economic lot size was computed by using the average weekly demand of 92.1 units for the entire requirements schedule. Note, too, that the average inventory for each period was used in computing the inventory carrying cost.

This example illustrates several problems with the EOQ procedure. When the demand is not equal from period to period, as is often the case in requirements planning forecasts, one of the assumptions underlying the EOQ formula is violated. Since demand does not occur at a constant rate, as is assumed by the EOQ formula, the restriction of fixed lot sizes results in larger inventory carrying costs. This occurs because of the mismatch between the order quantities and the demand values, causing excess inventory to be carried forward from week to week. As an example, 41 units are carried over into week 6 when a new order is placed.

In addition, the order quantity must be increased in those periods where the demand exceeds the economic lot size plus the amount of inventory carried over into the period. An example of this occurs in week 7. This modification is clearly preferable to the alternative of placing orders earlier to meet the demand in such periods, since this would further increase the inventory carrying costs. Likewise, the alternative of placing multiple orders in a given period would needlessly increase the ordering cost.

Finally, the use of the average weekly demand figure in computing the economic lot size ignores a considerable amount of other information contained in the requirements schedule. This information has to do with the magnitude of demand. For instance there appear to be two levels of component demand in this example covering weeks: 1) 1-4 and 10-12 and 2) 5-9.

[5] If an order is placed for 50 units in week 10, rather than for an economic lot size of 166, the total cost for this example may be reduced to $4171. This would, however, require the use of a more complex decision rule in actual applications.

Week Number	1	2	3	4	5	6	7	8	9	10	11	12
Requirements	10	10	15	20	70	180	250	270	230	40	0	10
Order Quantity	20		35		250		520		270			10
Beginning Invt.	20	10	35	20	250	180	520	270	270	40	0	10
Ending Invt.	10	0	20	0	180	0	270	0	40	0	0	0

Ordering Cost: $1800

Inventory Carrying Cost: 2145

Total Cost: 3945

Table 3—Periodic Order Quantity Example

By computing an economic lot size for each of these two time intervals, and placing orders accordingly, the total cost can be reduced to $3855. Yet, this proposal would be much more difficult to implement because the determination of different demand levels would require a very complex decision rule. The Part Period Balancing procedure (to be described in a later section of this paper) is a much simpler means of accomplishing the same objective.

Periodic Order Quantities: One way of reducing the high inventory carrying cost associated with fixed lot sizes is to use the EOQ formula to compute an economic time interval between replenishment orders [10]. By dividing the EOQ by the mean demand rate in the example above, this time interval would be approximately two weeks (166/92.1 = 1.8). When this procedure is applied to the example, as is shown in Table 3, it yields the same number of orders as the EOQ procedure, but with lot sizes ranging from 20 to 520 units. Consequently, the inventory carrying cost has been reduced by 30%, thereby improving the total cost of the 12 week requirements schedule by 19% in comparison with the EOQ result above.

Although the Periodic Order Quantity procedure improves the inventory cost performance by allowing the lot sizes to vary, like the EOQ procedure it, too, ignores much of the information contained in the requirements schedule. That is, the replenishment orders are constrained to occur at fixed time intervals, thereby ruling out the possibility of combining orders during periods of light product demand, e.g. during weeks 1 through 4 in the example. If, for example, the orders placed in weeks 1 and 3 were combined and a single order was placed in week 1 for 55 units, the combined costs can be further reduced by $160 or 4%.

Part Period Balancing: The Part Period Balancing procedure described by Gorham [4] uses all of the information provided by the requirements schedule.[6] In determining the lot size for an order, this procedure tries to equate the total costs of placing orders and carrying inventory. This point can be illustrated by considering the alternative lot size choices available at the beginning of week 1. These include placing an order covering the requirements for:

a) week 1 only
b) weeks 1 and 2
c) weeks 1, 2, and 3
d) weeks 1, 2, 3, and 4
e) weeks 1, 2, 3, 4, and 5
etc.

The inventory carrying cost for these alternatives is shown below. These calculations illustrate the manner in which we have changed the procedure suggested by Gorham to accommodate the average inventory carrying cost criterion rather than the end of period criterion.[7] Thus, the ordering plans produced by this procedure can now be directly compared with those obtained with the EOQ procedure.

a) ($2) . [(½) . (10)] = $10
b) ($2) . [(½) . (10) + (1½) . (10)] = $40
c) ($2) . [(½) . (10) + (1½) . (10) + (2½) . (15)] = $115
d) ($2) . [(½) . (10) + (1½) . (10) + (2½) . (15) + (3½) . (20)] = *$255*
d) ($2) . [(½) . (10) + (1½) . (10) + (2½) . (15) + (3½) . (20) + (4½) . (70)] = $885

In this case, the inventory carrying cost for alternative d), ordering 55 units to cover the demand for the first four weeks, most nearly approximates the ordering cost of $300. Therefore an order should be placed at the beginning of the first week and the next ordering decision need not be made until the beginning of week 5.

When this procedure is applied to the example shown in Table 4, the total inventory cost is reduced by $500 or by 13% of the cost obtained with the Periodic Order Quantity procedure. Notice that this procedure permits both the lot size and the time between orders to vary. Thus, for example, in periods of light product demand this procedure results in smaller lot sizes and longer time intervals between orders than for periods of high demand. This results in lower inventory related costs.

Despite the fact that this procedure utilizes all of the information available, it will not always yield the minimum cost ordering plan. Although this procedure can produce low cost ordering plans, it may miss the minimum cost plan since it does not evaluate all of the possibilities for ordering material to satisfy the demand in each week of the requirements schedule. This point is illustrated by the example shown in the next section.

[6]A more sophisticated version of this procedure, involving a look-forward and look-backward technique, is described by Plossl and Wight [10].

[7]Note that the inventory carrying cost for alternative a) is:
$(\$2) \cdot \left(\frac{10 + 0}{2}\right) = (\$2) \cdot (1/2) \cdot (10)$

Week Number	1	2	3	4	5	6	7	8	9	10	11	12
Requirements	10	10	15	20	70	180	250	270	230	40	0	10
Order Quantity	55				70	180	250	270	270			10
Beginning Invt.	55	45	35	20	70	180	250	270	270	40	0	10
Ending Invt.	45	35	20	0	0	0	0	0	40	0	0	0

Ordering Cost: $2100
Inventory Carrying Cost: 1385

Total Cost: $3485

Table 4—Part Period Balancing Example

Wagner-Whitin Algorithm: One optimizing procedure for determining the minimum cost ordering plan for a time phased requirements schedule is the Wagner-Whitin Algorithm [1,2,13]. Basically, this procedure evaluates all of the possible ways of ordering material to meet the demand in each week of the requirements schedule. We will not attempt to describe the computational aspects of the Wagner-Whitin Algorithm, since these are presented elsewhere [2,13]. Rather, we shall note the difference in performance between this procedure and the Part Period Balancing procedure.

When the Wagner-Whitin Algorithm is applied to the example, the results of which are shown in Table 5, the total inventory cost is reduced by $240 or 7 % in comparison with the ordering plan produced by the Part Period Balancing procedure in Table 4. The difference between these two plans occurs in the lot size ordered in week 9. The Part Period Balancing procedure did not consider the combined cost of placing orders in both weeks 9 and 12. By spending an additional $60 to carry 10 units of inventory forward from week 9 to 12, the $300 ordering cost in week 12 is avoided. In this case a savings of $240 in total cost can be achieved. This increase in the number of ordering alternatives considered, however, clearly increases the computations needed in making ordering decisions.

PERFORMANCE COMPARISON PROBLEMS

After observing the inventory cost performance obtained with these four ordering procedures in the example above, one might conclude that the first three procedures should not be considered for inclusion in a requirements planning system since the Wagner-Whitin Algorithm will guarantee an optimal solution. Yet, there are two problems with the Wagner-Whitin Algorithm.

In the first place, although the Wagner-Whitin Algorithm has been avail-

Week Number	1	2	3	4	5	6	7	8	9	10	11	12
Requirements	10	10	15	20	70	180	250	270	230	40	0	10
Order Quantity	55				70	180	250	270	280			
Beginning Invt.	55	45	35	20	70	180	250	270	280	50	10	10
Ending Invt.	45	35	20	0	0	0	0	0	50	10	10	0

Ordering Cost:	$1800
Inventory Carrying Cost:	1445
Total Cost:	3245

Table 5—Wagner-Whitin Example

able for some time, it is rarely used in practice. Instead, one finds numerous applications of the first three procedures [8,10]. Production managers often maintain that an ordering procedure for a requirements planning system should be: 1) simple to understand and implement and 2) efficient in terms of computing time because of the size of the inventory files in most systems.

In view of these factors, a more appropriate performance comparison would involve both inventory cost and computational criteria. That is, the analysis should indicate the tradeoff one is making between inventory cost performance and computing time when simple decision rules are employed. Such an analysis would involve comparing the inventory cost obtained with each procedure with the optimum results produced by the Wagner-Whitin Algorithm for a given ordering problem. This proposal leads, however, to a second problem.

The second problem with the cost comparison above is that we are generalizing from a single set of problem parameters. That is, a better comparison of ordering procedures would consider their performance over a wide range of cost and demand parameters. Several papers, dealing with a comparison of the Economic Lot Size and Wagner-Whitin models, have noted that the difference in performance between these approaches depends upon the variability of the demand data [2,6,12]. That is, as the assumption of a constant, known demand rate is removed, the performance of the Economic Lot Size model declines relative to the Wagner-Whitin Algorithm.

The most systematic approach to the problem of comparing alternative ordering procedures over a range of parameter values developed so far has been suggested by Kaimann [7]. We think that an extension of his method will provide considerable insight in the comparison of alternative ordering procedures for use in actual situations. We shall illustrate this approach using the example above, as well as several additional examples provided by Kaimann, in the remaining section of the paper.

EOQ/$\bar{D}$ Ratio	Procedure	Coefficient of Variation 0	.293	.718	1.410	3.310
.73	Economic Order Quantity	1681	1681	1585	1633	1153
	Periodic Order Quantity	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Part Period Balancing	1681	1681	1585	1597	1153
	Wagner-Whitin Algorithm	1681	1681	1557	1589	1153
1.0	Economic Order Quantity	2209	2915	2601	2655	1197
	Periodic Order Quantity	2209	2209	2025	2117	1197
	Part Period Balancing	2209	2209	2025	1961	1197
	Wagner-Whitin Algorithm	2209	2209	1953	1941	1197
1.14	Economic Order Quantity	3612	3085	3275	3105	1225
	Periodic Order Quantity	2545	2545	2305	2425	1225
	Part Period Balancing	2545	2545	2305	2205	1225
	Wagner-Whitin Algorithm	2545	2505	2205	2145	1225
1.5	Economic Order Quantity	3859	4873	3747	3799	1311
	Periodic Order Quantity	3447	3491	3145	3381	1311
	Part Period Balancing	3577	3359	2933	2787	1311
	Wagner-Whitin Algorithm	3447	3353	2871	2681	1311
1.82	Economic Order Quantity	5120	5435	4951	4865	1405
	Periodic Order Quantity	4011	4055	3615	3945	1405
	Part Period Balancing	4011	4055	3545	3485	1405
	Wagner-Whitin Algorithm	4011	4055	3435	3245	1405

Table 6—Total Inventory Cost Performance

PERFORMANCE COMPARISON FRAMEWORK

In comparing the Economic Order Quantity and the Wagner-Whitin procedures, Kaimann [7] varied the problem parameters systematically along two dimensions: the coefficient of variation of the product demand in the requirements schedule and the ratio of the ordering and inventory carrying costs (S/C_I).[8] The coefficient of variation describes the degree of variation in the demand data and is useful in indicating those cases where the EOQ procedure results in higher costs than the Wagner-Whitin Algorithm because of non constant demand. A sharper distinction can, however, be drawn between

[8] The coefficient of variation: $V_D = \sigma_D / \bar{D}$; where $\bar{D}$ is the average weekly demand and σ_D is the standard deviation of weekly demand.

Week	Data Sets 1	2	3	4	5
1	92	80	50	10	0
2	92	100	80	10	0
3	92	125	180	15	0
4	92	100	80	20	0
5	92	50	0	70	0
6	92	50	0	180	1105
7	92	100	180	250	0
8	92	125	150	270	0
9	92	125	10	230	0
10	92	100	100	40	0
11	92	50	180	0	0
12	93	100	95	10	0
	1105	1105	1105	1105	1105
Standard Deviation:	0	27.0	66.1	130.0	305.0
Coefficient of Variation:	0	.293	.718	1.410	3.310

Table 7—Demand Patterns for Investigation

the performance of these two procedures if the ratio of the economic order quantity to the average period demand (EOQ/$\bar{D}$) is substituted for the inventory cost ratio (S/C_I) used by Kaimann. The EOQ/$\bar{D}$ ratio measures the degree of mismatch between integral multiples of product demand and explains the large inventory carrying costs exhibited in some applications of the EOQ procedure.

When Kaimann's examples are viewed using this framework, there are several important differences between his conclusions and ours. In order to illustrate these differences, we have extended the example presented earlier. In all, we have computed the total inventory cost for 25 different sets of data, using the same methods that were employed in Tables 2-5. The results of this analysis are shown in Table 6. The cost and demand data used in preparing this table are provided in Tables 7 and 8. Table 6 presents a performance comparison of the four ordering procedures for selected parameter values in the [illegible] range: $.73 \leq EOQ/\bar{D} \leq 1.82$ and $0 \leq V_D \leq 3.31$. A direct comparison of the percentage difference between the results obtained with the three simple decision rules and the optimum results produced by the Wagner-Whitin Algorithm is shown in Table 9.

Ratio of EOQ to Average Weekly Demand (EOQ/$\bar{D}$)	EOQ	Ordering Cost	Inventory Carrying Cost Per Unit Per Week
.73	67	$ 48	$2
1.00	92	92	2
1.14	105	120	2
1.50	138	206	2
1.82	166	300	2

Source: Kaimann, R.A., "EOQ vs. Dynamic Programming—Which One to Use for Inventory Control?", *Production and Inventory Management*, 4th Qtr., 1969.

Table 8—Inventory Cost Parameters

EOQ/$\bar{D}$ Ratio	Procedure	Coefficient of Variation 0	.293	.718	1.410	3.310
.73	Economic Order Quantity	0	0	2.05	2.76	0
	Periodic Order Quantity	0	0	2.05	2.76	0
	Part Period Balancing	0	0	2.05	0.005	0
1.00	Economic Order Quantity	0	31.96	33.17	36.78	0
	Periodic Order Quantity	0	0	3.68	9.06	0
	Part Period Balancing	0	0	3.68	1.03	0
1.14	Economic Order Quantity	41.92	23.15	48.52	44.75	0
	Periodic Order Quantity	0	1.59	4.53	13.05	0
	Part Period Balancing	0	1.59	4.53	2.79	0
1.50	Economic Order Quantity	11.95	45.33	30.51	41.70	0
	Periodic Order Quantity	0	4.11	9.54	26.10	0
	Part Period Balancing	3.78	0.17	2.15	3.95	0
1.82	Economic Order Quantity	27.64	34.03	44.13	49.92	0
	Periodic Order Quantity	0	0	5.24	21.57	0
	Part Period Balancing	0	0	3.20	7.39	0

Table 9—Percent Increase in Total Inventory Cost: EOQ, POQ, PPB vs. Wagner-Whitin

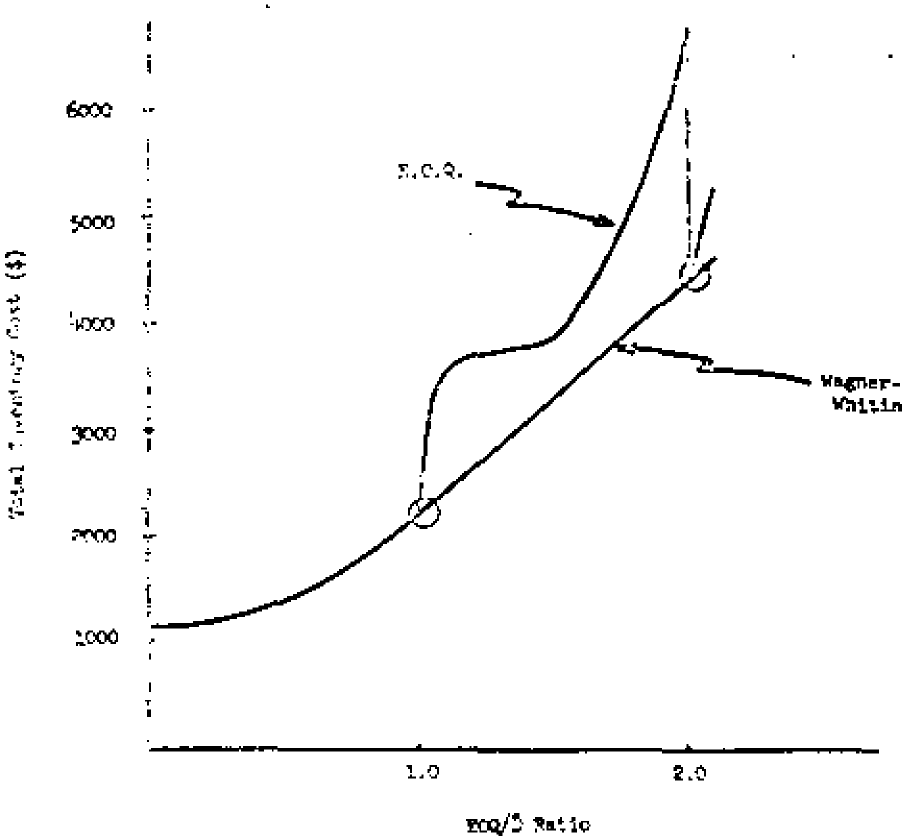

Figure 1—Total Inventory Cost vs EOQ/$\overline{D}$ Ratio for the Economic Order Quantity and Wagner-Whitin Procedures when VD = 0

Economic Order Quantity: The analysis shown in Table 6 indicates that when the Economic Order Quantity procedure is applied to the discrete demand data in a requirements schedule, there are two conditions where the EOQ procedure yields the same results as the Wagner-Whitin Algorithm. One condition in which this occurs is when the demand is uniform over the requirements schedule, i.e. the coefficient of variation is zero, and the economic order quantity is an integer multiple of the average weekly demand. The EOQ/$\overline{D}$ = 1.0 and $V_D = 0$ element in Table 6 provides one example of this condition.

To better illustrate this condition we have prepared additional examples that extend the range of EOQ/$\overline{D}$ values considered in Table 6 for the case when $V_D = 0$. These results are plotted in Figure 1. This graph shows that the EOQ procedure leads to higher total costs than the Wagner-Whitin Algorithm except when the EOQ/$\overline{D}$ ratio assumes integer values or when EOQ/$\overline{D}$ ratio is less than 1.0, in which case weekly orders are placed. In no case is the Wagner-Whitin procedure more costly than the EOQ procedure as is suggested by Kaimann [7,pp.71-74]. This fact follows directly from the assumption that orders can only be placed and received at the discrete time intervals defined by the requirements schedule.

The higher total cost performance of the economic order quantity procedure relative to the Wagner-Whitin Algorithm in Figure 1 is largely explained by the mismatch between the economic order quantities and the weekly demand, causing higher inventory carrying costs. The dip in the total cost curve for the EOQ procedure which occurs near the EOQ/$\overline{D}$ = 1.5 point in Figure 1 may be surprising at first. This happens because as the magnitude of the economic lot size increases, the extra inventory carried over from week to week soon becomes sufficient to eliminate one or more weekly orders. When the EOQ is 1.5 times the average weekly demand, in a constant demand schedule, an order is avoided every third week. Since orders can not be placed every second week until the EOQ/$\overline{D}$ ratio equals 2.0, the total inventory cost increases rapidly after EOQ/$\overline{D}$ equals 1.5.

A second condition in which the EOQ procedure and the Wagner-Whitin Algorithm yield the same results occurs when the coefficient of variation becomes very large, i.e. $V_D = 3.31$ in this example. This happens when extreme variations occur in the demand data and there is a marked degree of spikedness in the requirements schedule. The demand schedule shown in data set 5 in Table 7 provides a good illustration of this point. In such cases the economic lot size is not sufficient to meet the weekly demand. It is less expensive to simply increase the order quantity, rather than to initiate two or more orders for a peak demand period. The orders are placed to meet the weekly demand and the results obtained with both procedures are the same. We have plotted the data in the last row of Table 6 to illustrate this point. This graph is shown in Figure 2.

Kaimann's results indicate that the EOQ curve in Figure 2 should be a straight line, extending horizontally from a point on the total inventory cost axis.[9] This would reflect an increasing difference in total cost between the EOQ and the Wagner-Whitin procedures. Yet, our results indicate that there is a clear advantage to modifying the EOQ procedure as the degree of spikedness in the requirements schedule increases. Although the coefficient of variation does not measure the degree of spikedness in the demand data directly, it is a good approximating variable to signal the need to modify the EOQ approach.

Periodic Order Quantities and Part Period Balancing: Although the results shown in Table 9 indicate a close correspondence between the performance of these two procedures and the Wagner-Whitin Algorithm, the data

[9] This point is computed using the total cost expression for the static economic order quantity model and assumes that the time between successive orders is not restricted to integer values.

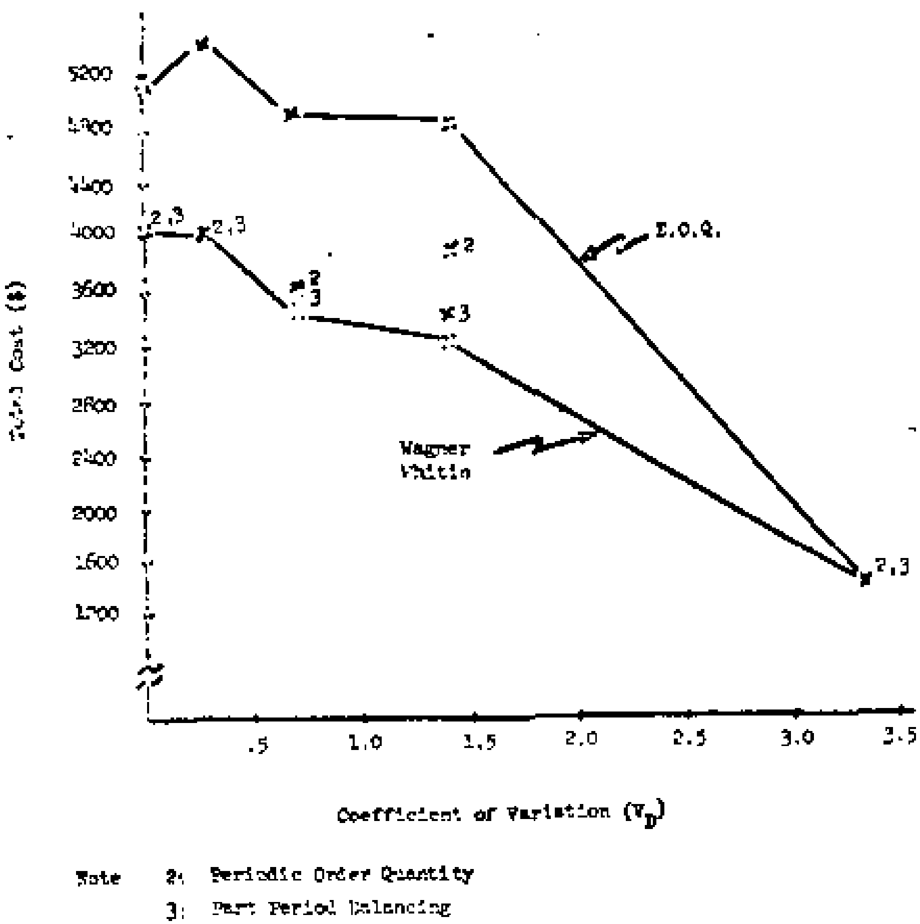

Figure 2—Total Inventory Cost vs Coefficient of Variation for an Ordering Cost of $300 and EOQ/$\bar{D}$ Ratio of 1.52

is not sufficient to draw any firm conclusions. In addition to its simplicity, the Part Period Balancing procedure did provide low cost ordering plans in these examples. One might therefore hypothesize that this procedure would represent an effective tradeoff between inventory cost and computing time performance for a requirements planning system.

CONCLUSIONS

The production manager clearly has a number of options in choosing an ordering procedure for a requirements planning system, ranging from the use of simple decision rules to optimizing procedures. The procedure he chooses will largely depend upon the emphasis he places on three criteria: inventory cost performance, computational efficiency, and procedural simplicity. To provide data for a more informed decision with regard to these criteria, the method of evaluating alternative ordering procedures should be broadened to include both: a range of cost and demand parameter values and the amount of computing time required to make ordering decisions. We believe that the analytical framework proposed in this paper is one step toward a more systematic analysis.

In a second paper we will report a simulation analysis in which this analytical framework was used to analyze the four ordering procedures described in this paper. Specifically, these simulation experiments were directed toward a more extensive exploration of the total inventory cost surface illustrated in Table 6 of this paper, and included both inventory cost and computing time criteria. In particular, two questions were analyzed in these experiments.

a) What is the magnitude of the difference between each of the three procedures and the Wagner-Whitin Algorithm with respect to: inventory related costs and computing time?
b) Can the differences observed for these two measures be accounted for by changes in the coefficient of variation or the EOQ/$\bar{D}$ ratio?

This analysis is directed toward improving the manager's ability to make better decisions with regard to the tradeoff between inventory cost and computing time in choosing an ordering procedure for a requirements planning system.

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About the Author—

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Formerly, Dr. Berry was employed by the General Electric Company as a member of the manufacturing training program, a supervisor in production in the Industry Control Department, and as a computer systems specialist in the same department. Presently, he is engaged in teaching and research in the area of production planning, scheduling, and inventory control. He is a member of APICS, TIMS, ORSA, and AIIE.

MATERIALS REQUIREMENTS PLANNING A HOPE FOR THE FUTURE OR A PRESENT REALITY -- A CASE STUDY

L. J. Burlingame
Twin Disc, Incorporated

Dr. Joseph Orlicky started a three-session series of presentations on Materials Requirements Planning with a talk entitled "Requirements Planning Systems: Cinderella's Bright Prospects for the Future" just one year ago in Cincinnati. This is a rather ironic title for Joe to use as he was running a Requirements Planning System nearly ten years ago. Not only was the system running, but a system derived from this one is still in use today in the same plant. Thus we have an example of ten years of history on Cinderella's future.

Two years ago in New York, just prior to the APICS conference, a workshop on "Materials Requirements Planning" was led by George Plossl and Oliver Wight for companies using this technique. The proceedings of this workshop have been published as part of the APICS Special Report, "Material Requirements Planning by Computer." Anyone interested in Requirements Planning should, I believe, obtain a copy of this report.

In this book, there are nine case studies of companies which had systems up and running two years ago. The results for these nine have been nothing short of spectacular. There have been 20 to 30% reductions in inventory, up to 20% improvements in customer service, and important cost reductions.* This is even more significant when you consider the diverse businesses represented. These companies go all the way from mass production to classical job shops. They go from heavy industry to electronics. The same basic technique yields positive results.

I am obviously making the case that Material Requirements Planning is a proven tool of the present. I am prepared to support the claim that under no condition can Requirements Planning be worse than Statistical Inventory Control. There are conditions under which it may be no better, but I feel that these are few in a manufacturing environment. The principle of Dependent vs Independent Demand is involved here and Dr. Orlicky has covered this a lot better than I could.

There is, at this time, a relatively new dimension which makes the picture still more favorable. Several computer manufacturers have made program packages available to take a great deal of the programming work out of Requirements Planning. The best known of those is IBM's PICS. This system has been successfully installed in several companies and it has been working for over three years. When you add to all of the above, the vastly improved computer capability available today compared to ten years ago, it would seem that companies by the hundred would be turning to this method.

The above is, however, not so. Progress at implementation of this well-known and proven technique is relatively slow. Why? The answer is, of course, very simple. George Plossl, in his Newsletter No. 7, gave the key in eight words -- "Systems make it possible - people make it happen." One Newsletter later, Oliver Wight said, "The odds are 20 to 1 PICS won't work for you." Please be sure to stress the YOU. Cinderella is here and getting old waiting for you.

*Note: See pages 19 and 20 of the report.

EXHIBIT 1.

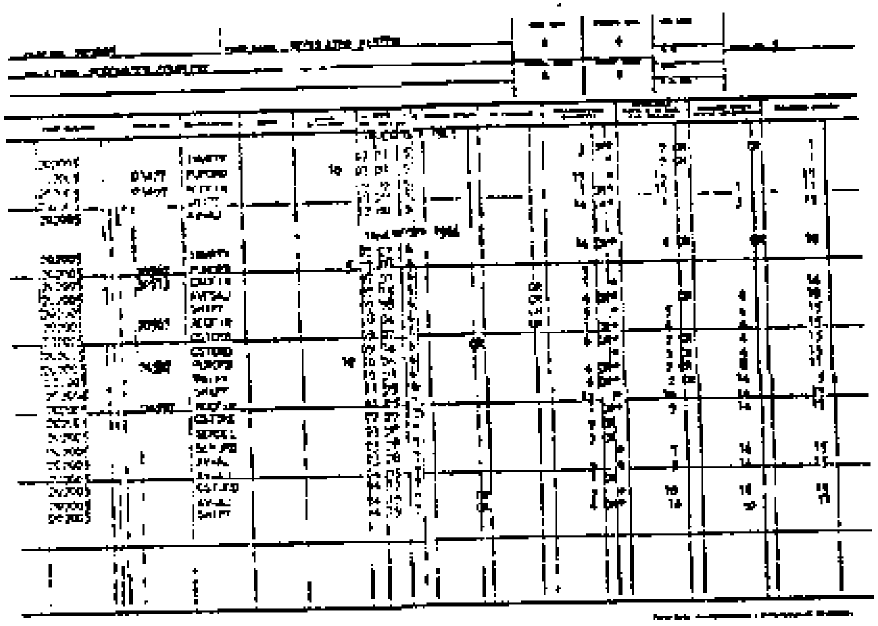
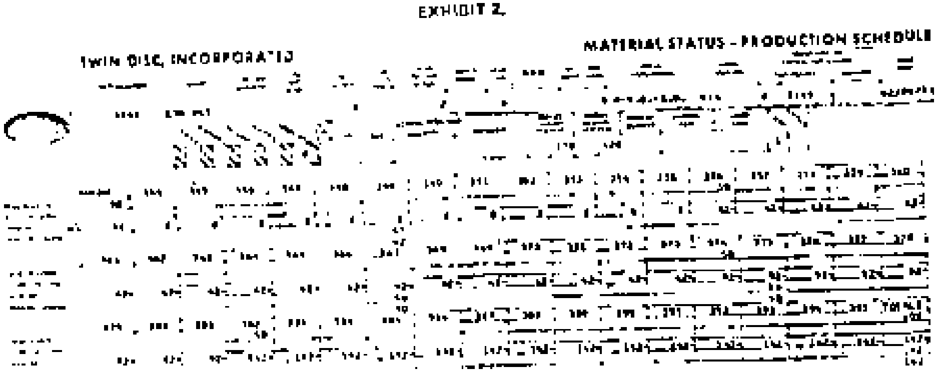
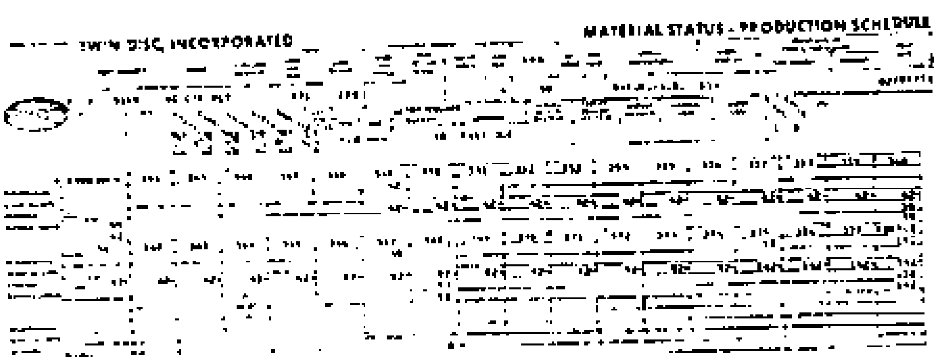


EXHIBIT 2.



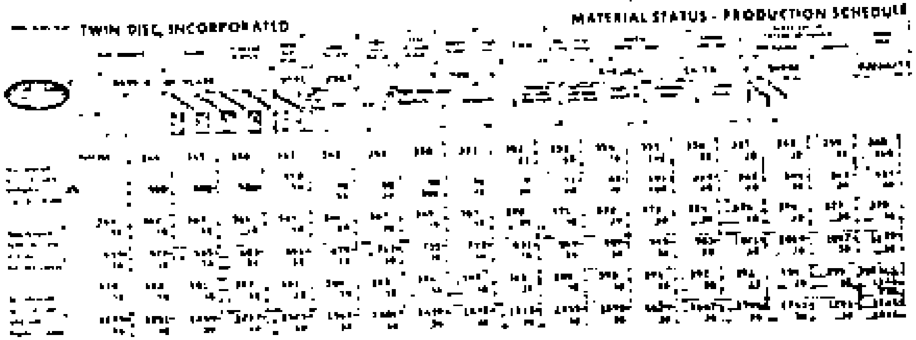


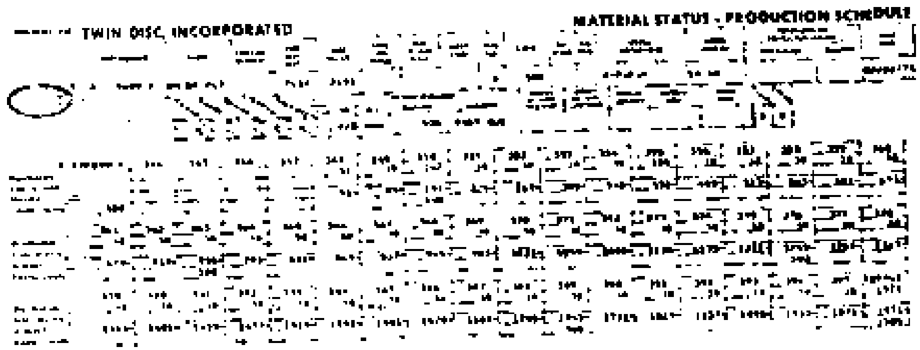
Since philosophy is one thing and practice another, I would like to introduce you to Twin Disc, Incorporated and show you a real live Requirements Planning System. Twin Disc has sales over $60,000,000 and manufactures power transmission equipment for a variety of industries, the largest of which is construction machinery. The system you will see is 7-1/2 years old, although it has had several major revisions. It was started on an IBM 1401 computer and is run today on a 360/40. We programmed it ourselves since PICS was not available in 1964. The most outstanding difference between our system and PICS is that we use net change while PICS uses regeneration. Twin Disc is one of the companies whose results are given on pages 19 and 20 of the Special Report.

Exhibit 1 is a copy of Twin Disc's reorder point system which was in use from the late 1930's until 1964 in Racine and 1968 in Rockford. We were unable to include the Rockford Plant in the new system until the 360 replaced the 1401. This system was quite a good one of its type and had only two real problems. The worst was that it took two to three weeks to update the system. This meant a lag of, at best, two weeks to explode a level of a bill of material. Some of our bills have ten levels. Entering an order took 20 weeks! We, obviously, had to develope manual short cuts, but these, at best, are poor substitutes for doing the job right. The other problem was the lack of timing. We knew that we needed material but we did not know when we needed it. Notice that on 8/4/66, we received five pieces of this part. This brought inventory up to 15 pieces. It was not until 10/28/66 that even one piece was used and not until 11/29/66 that the inventory fell below the 10 pieces that had been in stock on 8/4/66. That was real inventory turn?

Exhibit 2 is an example of two levels of a bill of material. It is also an example of a very simple dependent demand item. The first line that starts under Part Number is self-explanatory. The second line starts with some indicated action blocks. This is a copy of an Exception Action Report. For this exhibit, we made an inquiry and its box has an "X" in it. No action is indicated. The rest of the line should explain itself. We call these two lines "Master Information". Below, there are three sets of four lines each of variable information. This information goes ten weeks into the past, has the current week, and 89 future weeks. This format has the accumulated past due, the current week, and 50 future weeks. There are ten optional formats for this information. We will see two others later. The consecutive numbers starting with "344" are week numbers. When we started this system, we started with Week 300 and when we get to 999, we will start over. The next line, "Requirements", shows in time frames all of the requirements for this part. These can be caused by customer or service orders at a higher level, the same at this level, safety stock at any level, or sales forecast at any level. In short, it is the number of pieces we need to fill all demands. The next line is called "Scheduled Receipts". These are open purchase orders for a purchased part and work-in-process inventory for a manufactured part. "Available" starts in the first space with on hand inventory, and is the result from there on of netting the inventory, scheduled receipts and requirements. Thus, the 50-piece requirement in "Past Due" nets against the 58 pieces in inventory and gives an available in Week 344 of +8. In the same way, the 50-piece requirement in Week 356 nets against the +8 and gives an available of -42. "Planned Orders" are nothing more than start dates. This part has a six-week lead time and our rules say a part should be scheduled to be received one week prior to need. Thus, the first need is in Week 356 and if we subtract six weeks from Week 355, we have a planned order in Week 349. This is the last date that parts can be started through the shop if they are to be done in Week 355 and available in Week 356. There are two 42's in Week 349. We carry two

EXHIBIT 3.





complete sets of inventory records for each part. I said, above, that all requirements were carried on Line 1. There is another record that carries only customer orders and service orders on Line 1. This record can then be said to be "pegged" to firm orders which can be identified by order number! The second 42 is the planned order line from the second record. An example of this second record will be discussed later.

The general subject of pegging is a complex one. I would like to point out a few items about this type of peg. If you try to peg at all levels with an exact peg to order numbers at an upper level, you will run into a very complex set of records at lower levels if there is much cross usage of parts. In our case, we would have several thousand pegs on some lower level parts and raw materials. To avoid this, most systems peg only one level down or peg only to Level "0". However, I think that, in something over 90% of the cases, it is important only to know the type of order, not the order number. If you accept this, you can cut out 99% of the trouble with pegging and get 90% of the good. Order numbers can be found at any time by implosion. In general, you have two choices to peg if you wish to break through forecasts, lot sizes, safety stock, etc. The first is to maintain a separate record for each type of peg for each item in inventory. This is what we have done for this one type of peg. You can see that this would get out of hand if you were to have six or ten types of peg. The other is to regenerate by special program, on request, any type of peg desired.

The lower half of Exhibit 2 shows the casting from which the part is made. (Note the * is part of the part number.) The 42-piece planned order above in Week 349 is a requirement of 42, Week 349, for th[illegible]sting. This shows the lead time offset. On this part, we sho[illegible]t only the inquiry but also an order suggestion and an expedite since Week 349 is within lead time. The suggested purchase order is for 50 pieces which is the order quantity for the casting. Therefore, there is a 50-piece planned order in the past due. Note, however, the second planned order is still the pegged 42 pieces. Page 19 of the Special Report refers to our practice of coding parts by vendor's machine center for inquiry purposes. The "DG" in the part name of this casting is a code for a foundry and a code for the type of molding.

This is, of course, an example of dependent demand. There are requirements for 200 pieces of the top level part over a time spread of 33 weeks. These demands come in four 50-piece increments. I think that this example points out, as well as anything can, the shortcomings of the sawtooth chart and traditional EOQ. Both techniques are based on the incorrect premise that demand will be constant.

Exhibit 3 shows the effect of safety stock on a requirements plan. In this case, the 500-piece safety stock has been deducted from "on hand" prior to the calculation of available. With no "on hand" and no "requirements", the first available is -500. At first glance, the casting would seem to be in the same condition as the one in Exhibit II, with a past due planned order. However, in this case, there is no pegged planned order and you can tell at a glance that this message comes from the fact that we are into safety stock at an upper level. There is no need, in this case, to try to bring in the castings in less than lead time. If you had a traditional reorder point system, however, I don't think that you could tell the difference between these two parts, and you would be putting equal emphasis on them. It is central to our system to be able to tell what would be nice to do and what must be done. I don't think that a sensible approach to Shop Floor Control or Purchasing Systems can be made until the Inventory Control System provides this data.

The inventory control rules used in our system or in any other system can be the user's own. Our system is not the lowest inventory system that can be devised with Requirements Planning. It was designed to yield a high degree of customer service. I would like to stress, however, that it is possible to go the other way. A 500-piece safety stock may seem high to you on an "A" item. It is there for reasons that have to do with a vendor and a customer; it is not a part of the system.

I will use Exhibit 4 to support my claim that even with independent demand, Requirements Planning can do the job as well as reorder points. The example part is an independent or nearly independent demand part. As such, exponential smoothing is used to forecast this part. The forecast, in this case, is 36 pieces per week and the smoothing constant is .15. This forecast is recalculated every four weeks. The program compares the actual requirements with the forecast and uses the greater amount to calculate the available, except in the first four weeks where it uses 20% of the forecast. This is easy to see if you look at the planned order line. All weeks with a 36 are the result of forecast, at least in part; the others are firm. Note the total at the end of the record where we have 1829 pieces in planned orders for this record, of which 189 are firm orders from the pegged record.

Exhibits 2 through 4 are examples of an exception report which is issued twice a week for those parts requiring action (order, cancel order, reschedule, etc.). This is the tool used for inventory control. Exhibit 5, on the other hand, is generated only on request and is used to review schedules. This format shows cust[illegible]r and service orders as requirements only. The planned order [illegible] of this information arrangement is the second planned orde[illegible] [illegible]e in

EXHIBIT 4.

TWIN DISC INCORPORATED — MATERIAL STATUS - PRODUCTION SCHEDULE

[illegible]

TWIN DISC INCORPORATED — MATERIAL STATUS - PRODUCTION SCHEDULE

[illegible]

Exhibits 2-4. In this way, a product line scheduler can look at the lower levels of any bill of material and see the availability of parts and raw materials, devoid of the distortions brought about by upper level safety stocks, order quantities, etc. This format is harder to read than the others because it is printed on plain paper to avoid the cost of preprinted forms, and ease of reading is unnecessary since only a few people need to know how.

The same information is available in Exhibit 6 as is available in Exhibit 5 with one exception. In Exhibit 5, all of the past due is collected in one summarized quantity for each line. This is good enough for a product scheduler, but a Shop Floor Control System needs to know, not only that a job is past due, but how far it is past due. Thus, the 21 pieces which are shown as past due in Exhibit 5 can be identified as 20 from Week 336 and 1 from Week 342. This format is printed out only rarely (mostly for examples such as this), but the computer makes use of the information to calculate critical ratio.

I think that you will agree that it is important for Purchasing to be able to separate firm customer requirements from requirements caused by inventory decisions and sales forecasts. It would be very nice to have all vendors deliver all material on the date requested, but we don't live in that sort of world. How many times have we heard people say, "Tell me how many you really need and when, and I'll get them." Material Requirements Planning can answer that question for both the buyer and the foreman. Exhibit 7 is a fairly standard Open Purchase Order Report which shows each buyer his open orders in vendor number and part number sequence. However, at the right of the page, under FWCEK and FQTY, he can find the last ditch date and quantity, delivery of which can prevent a late delivery to a customer. It is interesting to me to see, that, in every case, either the date or the quantity differs from those on the purchase order. This part of the report extends out

EXHIBIT 5.

[illegible]

EXHIBIT 6.

[illegible]

seven weeks. Since expediting is usually a telephone matter, no attempt is made to issue a formal reschedule for orders which are needed sooner than the schedule date shown within these seven weeks. One by-product advantage of this is the savings of 14 pieces of paper (Purchase Order Revision -- Receiving set), and the time required to prepare it, for each such case.

A "Fail Safe" report of this type can be generated by customer, product line, due date, type of order, etc. In this way, specific information, without extra unwanted items, can be generated on request. Thus, the pegging principles enumerated earlier have been put into practice.

When scheduling customer orders under our reorder point system, we were lucky to examine the inventory position of 10% of our parts. The other 90% were assumed to be in adequate supply. This worked most of the time because our people knew which 10% to check. However, when one of the other parts was in short supply, for any reason, the schedule date could be months too soon. Not only that, but when it was taking two to three weeks to update the system, the inventory records could, and did, show positive availability on parts which had been sold! These two problems sound stupid and funny, but they existed for us seven years ago and they exist for many of you today.

EXHIBIT 7.

[illegible]

EXHIBIT 8.

ORDER NUMBER	CUST. NUMBER	WEEK REQUIRED	WEEK ALLOCATED	PART NUMBER	QUANTITY	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

EXHIBIT 9.

[illegible]

EXHIBIT 10.

[illegible]

EXHIBIT 11

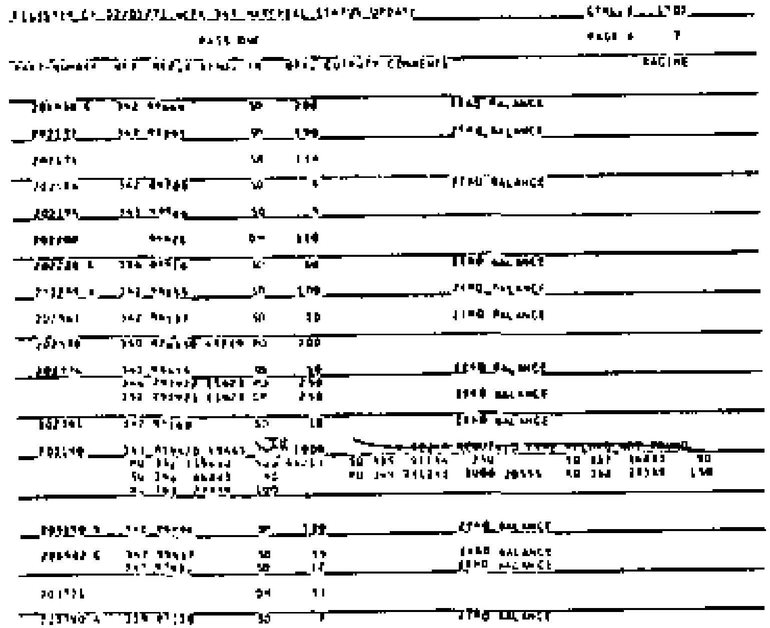
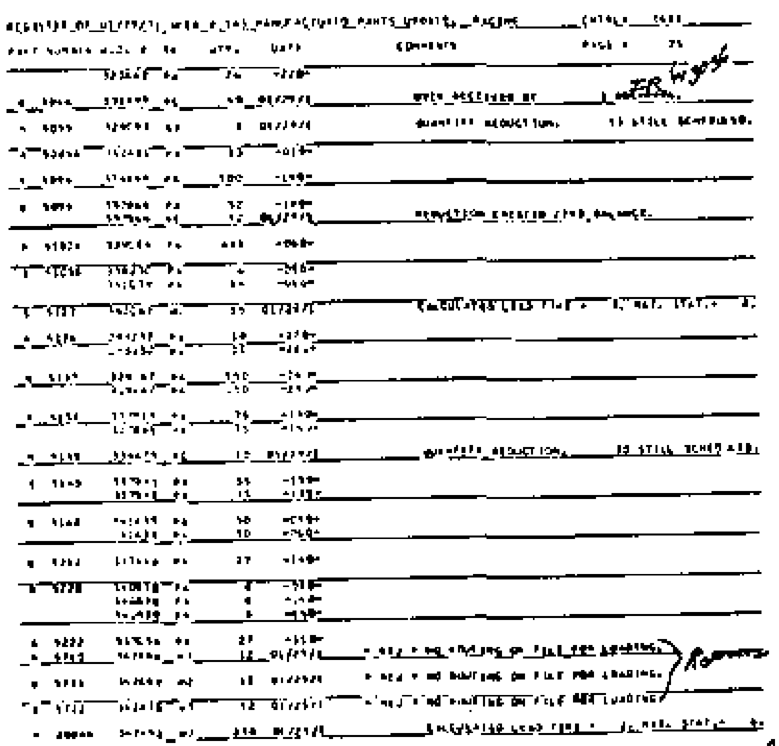


EXHIBIT 12



With inventory records setup having a time series, it is easy to see how the computer can be programmed to determine a deli[illegible] date after examining all components of an assembly. With net c[illegible]ge, it is also easy to see how the system can be updated completely after each individual order is entered. The actual program is very complex and uses 20K plus many hours of computer time each week. This would be out of line for many companies, but we feel that it is well worthwhile for us. Exhibit 8 is the output from this program which shows all orders entered, and it notes those which were not scheduled to the customer's request. This is indicated in the second column from the right. The right hand column shows the part number that caused us to fail to meet the customer's requested date. Orders which are so indicated are checked over by a product scheduler to be sure that the reschedule is necessary.

Exhibits 9 and 10 are an implosion and an explosion which explain themselves.

On the first page, I gave some attention to the failure rate of these systems and indicated that people were responsible for either failure or success. Details cannot be overlooked. Since the system is very quick to respond, it will compound errors faster than any other inventory system I know. Exhibits 11 and 12 show examples of two types of daily updates. On both of these sheets, the computer has been able to find errors. This is done by checking order numbers, part numbers, quantities, dates, etc., against each other. After these errors have been identified, the rule is that corrections must be made prior to processing another day's work. If a correction is not made, the error will appear on the next day's update. There have been three corrections made on these sheets.

The last exhibit is illustrative of another important feature of our system. Most reports are generated either by exception or by special request when the information is desired. We generate few traditional two foot high reports to sit on a desk until yellow, and which then are thrown out. This form is used to request the 11 most used optional reports. Except in an emergency, these are issued on an overnight basis.

This has been a rather quick introduction to Material Requirements Planning, and it has been necessary to skip much that is important. However, I feel that the use of actual examples, rather than madeup ones (even though they are more complex), makes the story more believable. This is a better way to control inventory, and it is also a better way to spread the necessary information throughout the organization. It belongs in the present, not the future.

EXHIBIT 11.

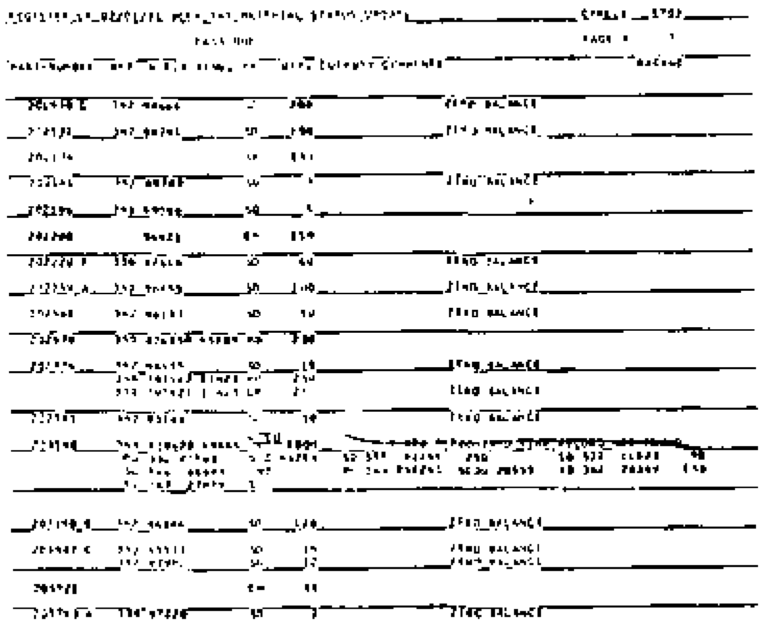


EXHIBIT 12.

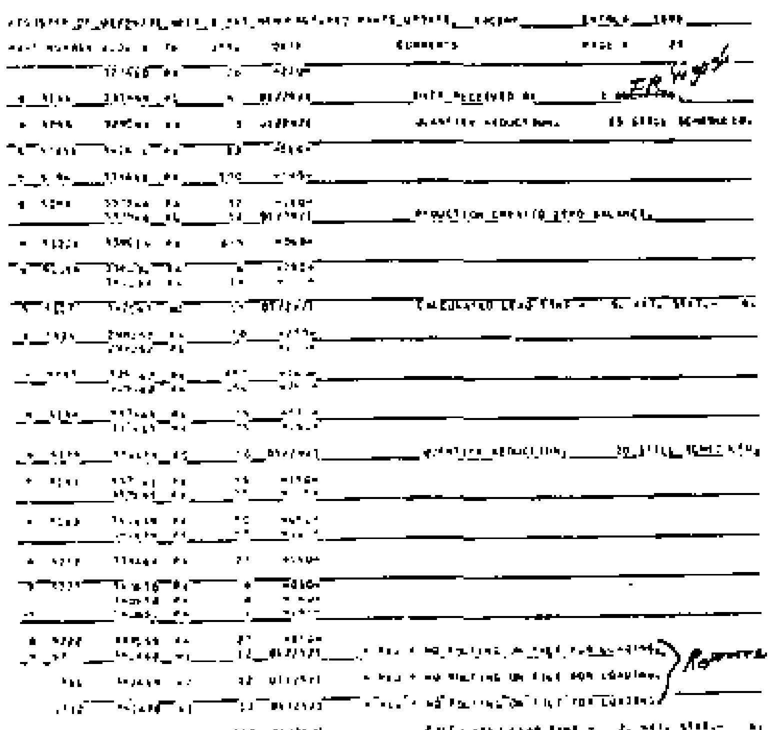


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EXHIBIT 13

TWIN DISC, INCORPORATED

REQUEST FOR COMPUTER INFORMATION

CODE: None

Date ________

Requested by ____

Code
- A — 1 Level Explosion
- B — Indented Explosion
- C — 1 Level Implosion
- D — Indented Implosion

Code
- E — Manufacturing Routing
- F — Random Action Inquiry
- G — Regular Material Status Inquiry
- H — Fail Safe [illegible]

Code
SPECIAL MATERIAL STATUS
- G1 — Customer Requirements Only
- G2 — 10 Week Past Due
- G3 — 10 Week PD & Cust. Req.

Type of Inquiry	PART NUMBER Columns 1	2	3	4	5	6	7	8	9	10	REMARKS

This article reprinted from the American Production and Inventory Control Society 1971 Conference Proceedings pp. 125-136.

About the Author --

L. J. Burlingame is presently Vice-President, Materials Management, for Twin Disc, Incorporated, Racine, Wisconsin, where a Time Phased Requirements Planning System has been in use since April of 1964. This system has recently been augmented with a Critical Ratio Dispatching System and an Infinite Capacity Loading and Capacity Planning System. Prior to his current assignment, he was Materials Manager, Production Control Manager, Industrial Engineer, Shop Foreman, and Project Engineer. He received an AB degree from Harvard in Physics in 1951 and an MBA from Harvard in 1956. He is the current President of the Milwaukee Chapter of APICS. His article, "Finite Capacity?" appeared in the second quarter, 1970 issue of Production and Inventory Management.

STOP: BEFORE YOU USE THE BILL PROCESSOR . . . . .

DAVE GARWOOD
Fisher Controls Company, Marshalltown, Iowa

Bill Processors are becoming increasingly popular software packages to load and maintain product structure data (bills of material) on computer files. The technical proficiency of these packages has been found to be excellent. But beware! Technical proficiency of software may not be the solution to your *real problem.* Your efforts — which are usually time consuming and costly — may be an exercise in futility and result in a "computerized system" which never achieves the promised, practical utility.

Do any of these statements sound familiar?

- "Our product has too many variations to forecast by end product for planning component requirements."
- "We have been working for four years and have still not achieved complete bill of material coverage."
- "Maintaining and indexing our bills of material is becoming too large to handle."

If so, the basic structure of your bills of material may be your real problem. The Bill Processor and computer speed *are not solutions* to your problem.

PROBLEM

Examine the need for and resulting requirements of bills of material. The advent of the computer has opened doors for application of some *potentially* profitable production and inventory control techniques — time phased requirements planning for instance. These techniques require a sound data base including a well documented product structure — Bills of Material. What role does the bill of material play in applying these techniques? *Coverage* — you must be able to quickly and accurately provide specific product definition with every sales order. But, *more important*, you must be able to use your bills of material to *translate* general, non-specific *product forecasts* down to specific part requirements.

The basic problem usually found in structuring bills of material is the fantastic number of combinations into which a relatively few parts can be assembled. For instance, consider an automobile which is assembled with 5 sub-assemblies — 1 of 20 motors, 1 of 5 transmissions, 1 of 20 interiors, 1 of 50 body styles, and 1 of 5 radios. Although *only 100* (20 + 5 + 20 + 50 + 5 = 100) *sub-assemblies* are *involved*, a total of *500,000* (20 X 5 X 20 X 50 X 5 = 500,000) *different automobiles could be assembled* — assuming that all combinations are practical. Sound impossible? A leading manufacturer of motor trucks reported in a recent article that over 32 quadrillion variations of *one* model were possible considering *only* 18 standard items such as engine, axle, brakes, etc. How about trying to forecast the specific models to be sold from the 2nd quarter forecast of 10,000 automobiles? Lots of Luck!

Some companies achieve bill of material coverage by starting with an existing bill, deleting various parts not required and adding new parts to form a new bill of material. The new bill is usually not identified with a unique number nor retained on permanent files. If it is identified and retained, it must be added to the index, which can become unwieldy. This technique – called "Add/Delete" – is error prone due to the manual intervention of correctly deleting and adding part numbers which are usually 6 – 12 digits long and introduces *transposition* errors. It also slows down the order entry process. But, the *prime shortcoming* is that it does not provide an adequate, historical data base to use in translating the forecast into specific part requirements. You may know for instance that Bill of Material Number 474 x 1 was used 40% of the time when Model 474 was sold but you don't know which parts (and with what frequency) were added and deleted. If you maintain a record of the exceptions, you are back to forecasting a multitude of specific end products (add/delete variations) with little certainty in the forecast accuracy.

Another solution sometimes recommended is to apply the 80–20 Law. Structure the 20% which represent 80% of the volume and structure the remaining 20% of the volume as the customer's orders are received. Great! Which 20% are the high volume products? They will be impossible to identify without first structuring all possibilities and examining their historical usage. In addition, 20% of 500,000 for the automobile manufacturer is still 100,000 bills of material requiring 500,000 (5 x 100,000) product structure records.

SOLUTION

The *best solution* is to adopt the *Modular Bill* of *Material concept*. The concept is to group parts which vary by the same product variables into a PPL (Partial Parts List). When a customer's order is received, an Order Entry Department determines the product variables required to satisfy the customer's requirements and selects the required PPL's. A simple computer program pulls the part numbers together from each PPL to compile the complete bill of material. This complete bill is stored *only* for the life of that customer's order.

Consider the automobile example discussed earlier. If a PPL were made for each motor, transmission, interior, body and radio, *only 100 bills of material* and 100 product structure records would be required. This is a 99% reduction in bills of material.

Indexing the bills of material *is simplified*. The index would be sub-divided by motor, transmission, interior, body style and radio. You make one selection from the 5 – 50 choices in each sub-division. This is much easier than finding the single bill of material from 500,000 possibilities!

Look how the *forecasting problem* has been *reduced*. Instead of trying to determine which of the 500,000 unique autos are to be sold from the 10,000 unit 2nd quarter forecast you need only to distribute the 10,000 unit forecast over 5 transmissions, and the same 10,000 units over 5 radios, the same 10,000 units over 20 motors, and so forth. The bill of material structure becomes the tool to translate general, nonspecific product forecast down to specific part requirements.

A common misinterpretation of this concept is that the parts on each PPL must be made into sub-assemblies. This is not true. The parts listed in each PPL are commonly used in the end product when a unique variation is selected but may never exist in a sub-assembly or even be possible to make as a sub-assembly. The PPL simply represents a set of parts to be combined with other parts to assemble an end product.

ADVANTAGES

The advantages with this approach are:

1) A tremendous *reduction in the number of bills of material*
2) An even greater *reduction in product structure records*
3) *Less maintenance* of the bills for engineering changes
4) *A simplified index* to the bills of material
5) The ability to *plan* individual *part requirements from the end product forecast*

Do you need the same safety stock inventory for radios and motors in the automobile? *Absolutely not!* The forecast for *each* of the 5 radios will be more accurate than for *each* of the 20 motors; therefore, the total safety stock inventory on motors will be greater than that of radios to protect against the greater uncertainty of the forecast for *each* motor.

PRACTICAL EXAMPLE

Fisher Controls Company manufactures products which are custom assembled with 30 to 100 parts. A staff of 5 – 10 spent three years creating 750,000 product structure records and achieved bill of material coverage for only 50% of our orders – the easy 50%! A management consultant suggested we consider the Modular Bill of Material concept. The concept is a practical solution to our bill of material dilemma.

Figure No. 1 is an example of the index used by our Order Entry Department to specify the PPL's required to build one of our products which is engineered for the customer's application. The *product variables* are indexed as an *ITEM*.

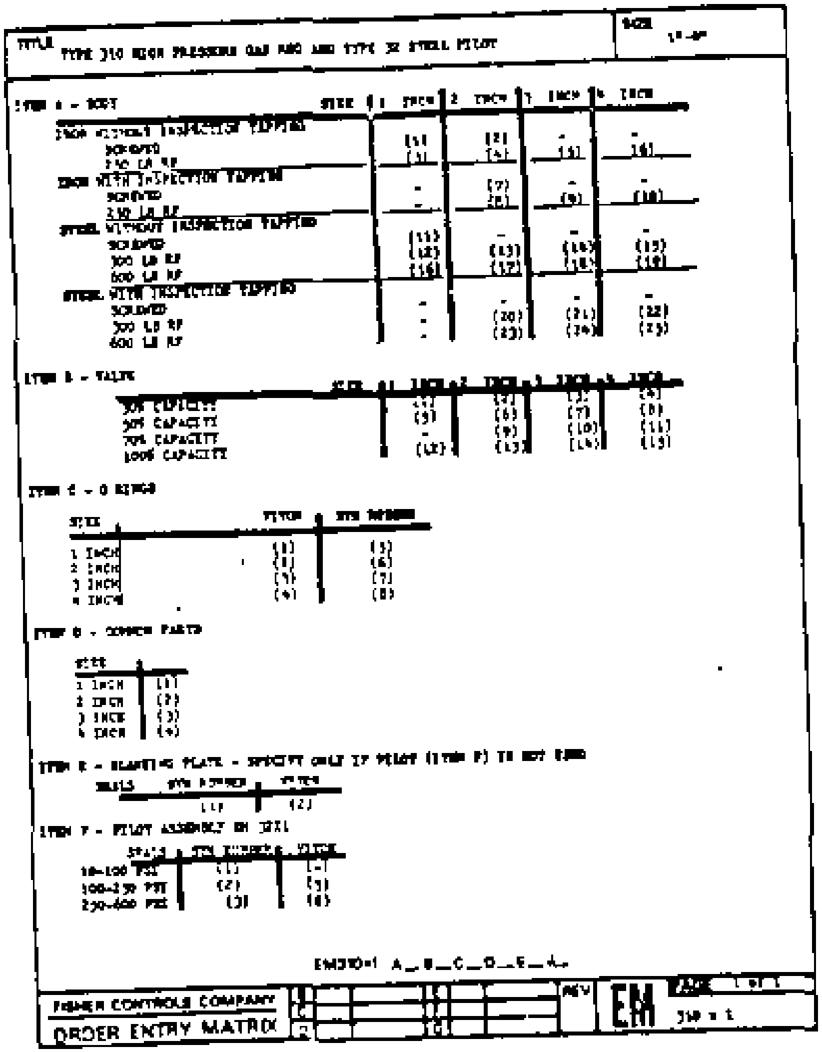

Figure 1 – Order Entry Matrix

One or more PPL's are available for selection in each ITEM. The numbers in parenthesis ( ) identify the PPL for a unique selection in each ITEM. The PPL's in ITEM A vary by body size, inspection tapping, and flange rating. The PPL's in ITEM B vary by the body size and valve capacity. Notice that the PPL's in ITEM D vary only by body size and are identified as "Common Parts." This product requires 30 parts to assemble an end product of any size – 20 of these parts are common to all units of a given body size. We have found some products which have a group of parts common to all product variations of a model.

Consider, for example, that a customer wants a 3 inch, 300 LB RF unit without inspection tapping, a 50% capacity valve, viton O-rings and a 100-250 psi pilot. Order Entry specifies an EM310 x *1A14 B7 C3 D3 F5.* Pre-loaded into our product structure file are the part numbers required for PPL's EM310 x *1A14*, EM310 x *1B7*, EM310 X*1C3*, EM310 x*1D3*, and EM310 xs,*1F5*. Data Processing keypunches the PPL numbers along with appropriate order identification. A complete bill of material is pulled together from the individual PPL's and printed for that order. It *is possible* to assemble *760 unique variations* of this one model by selecting acceptable combinations of PPL's from the Order Entry Matrix in Figure 1.

Table 1 lists some numbers for comparative analysis of the Modular Bill of Material concept versus the conventional bill of material approach. These numbers represent actual products manufactured by Fisher Controls Company.

MODEL	B/M APPROACH	NUMBER OF BILLS OF MATERIAL	PRODUCT STRUCTURE RECORDS
310	Modular	60	260
	Conventional	760	24,300
928	Modular	86	300
	Conventional	900	45,000
67F	Modular	40	100
	Conventional	138,000	4,838,400
657	Modular	40	3,300
	Conventional	80	72,200
E	Modular	1,150	2,000
	Conventional	250,000	3,110,000

Table 1 – Comparison of Modular Versus Conventional Bills of Material for Different Models.

The number of bills of material and product structure records for each model is substantially reduced with the Modular Approach. For example, Model 67F would require 138,000 bills of material to define all possible end products but only 40 with the Modular Approach. Since the number of parts per bill of material is substantially less with the Modular Approach, the reduction in product structure records is even greater (4,383,400 to 100). We have estimated 8 man-years to complete the project of changing our current product definition to the Modular Bill of Material format and achieve nearly 100% bill of material coverage — a feat which we had spent approximately 20 man years to achieve 50% coverage.

APPLICATION

Examine one of your products to see if some parts are commonly used together. A good way to examine your product for parts commonality is take a stack of bills of material for one product line and see if the same part appears on all of the bills or one or two (or three) parts appear on several bills. If they do, these are the parts common to the product variable on those bills and should be grouped into a PPL. Another good indicator of the applicability of the Modular Bill of Material concept to your product line is determine the number of variations into which one of your products can be assembled. If you find that your product can be assembled into many variations from a relatively few parts and a significant degree of parts commonality exists, your bills of material need restructuring before you use the Bill Processor.

CONCLUSION

Don't expect a Bill Processor to solve your bill of material structure problems. It will degenerate into another computer system illustrating programming competence but contribute little improvement in operating your business. Bills of Material are fundamental elements in the data base required for an effective material control system. Examine your bill of material structure. Be sure you will *achieve* the *coverage* required, you can *store, maintain* and *index* your bills and you can compute *specific part requirements* from end product forecasts.

ACKNOWLEDGEMENT

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DYNAMIC ORDER QUANTITIES

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Computer capacity and techniques have now reached the point where more and more companies are developing time series requirements planning systems. In these systems the requirements for a part will be expressed not as a rate per day, but rather as an array of varying requirements scattered out through time. Components of stocked assemblies will show intermittent usage based on the expected building of the assembly. A seasonal part would show a fluctuating usage. It is apparent that such erratic requirements could not be validly expressed as a rate per day nor could they be ordered economically with either a fixed quantity or fixed time period order quantity calculation. An ordering system is required which will develop economical orders in spite of this changing and intermittent usage.

Two methods of calculating dynamic order quantities are discussed in this article. Both are non-reiterative in that they step through the array of requirements only a single time, calculating a series of orders. These methods are considerably faster than reiterative methods which must try several alternative strategies before deciding on an ordering pattern.

The first method which is more well known and the most commonly used, searches for the least unit cost. In developing an order it steps through the requirements calculating the cost of inventory and setup per piece and it orders at the point where the unit cost is lowest. This method, in spite of its apparently unassailable logic, turns out upon analysis and comparison with other methods of ordering, to be a very uneconomical way of determining order quantities. It develops ordering patterns which result in excessive inventory and also excessive setup charges.

The second method is newer and not so commonly known. It is based on the same theory as the classic EOQ formula, i.e., that the least total cost is at the point where the inventory cost and setup cost are equal. This method consistently develops ordering patterns which result in considerably smaller inventory and setup charges than does the least unit cost method.

The following examples show the difference in the way the two methods would order. They show a very simple array of requirements and the computation of order quantities using the least unit cost method. Throughout these examples we are assuming:

Unit cost = C = \$1.00

Setup cost = S = \$40.00

Inventory carrying cost = I = .5% per week (25% per year)

The inventory cost is figured as follows:

The first requirement of 1000 is assumed to come to stock and be drawn for the next usage in the same week. Therefore it would not acquire any inventory cost.

The second requirement of 6000 would be held in inventory for three weeks which is equivalent to carrying 18000 parts for one week. The 18000 at .5% gives an inventory cost of \$90.00.

Week	Require-ments	Cum Reqts.	Weeks In Inv.	Reqts x Weeks	Inv. Cost @ .5%	Setup Cost	Total Cost	Unit Cost
1	1000	1000	0	0	0	40.00	40.00	.040
2			1					
3			2					
4	6000	7000	3	18000	90.00		130.00	.0186
5	1000	8000	4	4000	20.00		150.00	.0187

Figure 1

In the example of Figure 1, the least unit cost is at a quantity of 7000 where the unit cost is .0186 with a total cost of \$130. An inspection of the costs, however, reveals that it would be less expensive to setup and make the requirements for 6000 separately since then there would be a setup charge for \$40 rather than an inventory charge of \$90. This would result in \$50 less expense. The least total cost method would order this way because the inventory charge of \$0 is closer to the setup charge than is \$90. (There is no advantage to making part of the 6000 in order to achieve an exact balance of \$40 inventory and \$40 setup, since that would increase inventory but would not reduce setups.)

In Figure 2 the requirements have been switched around. Here the least unit cost is at a quantity of 6000 with a total cost of \$40. Again, an analysis of the costs reveals that it would cost \$40 to set up to make the 1000 in period 4 whereas if that quantity were combined with the initial requirement it would only cost \$15 in inventory charges. This would be a savings of \$25. The least total cost system would combine the 6000 in period 1 and the 1000 in period 4 (and more) because the cumulative inventory charges had not written off the setup charges.

These two examples, though admittedly rigged, do show the radical differences between these two methods. Many tests of these have been made using long arrays of requirements. A series of orders was devel-

Week	Require-ments	Cum Reqts.	Weeks In Inv.	Reqts. x Weeks	Inv. Cost @.5%	Setup Cost	Total Cost	Unit Cost
1	6000	6000	0	0	0	40.00	40.00	.0067
2			1	0	0			
3			2	0	0			
4	1000	7000	3	3000	15.00		55.00	.0078
5	1000	8000	4	4000	20.00		75.00	.0094

Figure 2

oped and the resulting cost of inventory and setup was computed. The least unit cost method was very erratic in its behavior. On one set of requirements it would develop low setup costs and high inventory costs, and on another set it might do just the reverse. However it never could obtain the balance between the two which resulted in lower total costs than were being achieved by the least total cost method.

From a more mathematical point of view the following are generalized expressions of the two methods. (The derivations of these are in the appendix.) In these

S = Setup cost

C = Unit cost of part

I = Inventory carrying charge per period

R_n = Requirement quantity in period n

n = Number of periods ordered or period number

Least unit cost:

The unit cost at period n + 1 will be less if

$$nR_1 + (n-1)R_2 + (n-2)R_3 + \ldots + 2R_{n-1} + 1R_n < \frac{S}{IC}$$

Therefore order out through time periods until the expression on the left becomes greater than S/IC.

Least Total cost:

$$0R_1 + 1R_2 + 2R_3 + \ldots + (n-2)R_{n-1} + (n-1)R_n = \frac{S}{IC}$$

C r at the point where the expression on the left is most nearl equ:l to S/IC.

Before going on, it might be a good idea to look at the expression S/IC which is the control factor in both formulas. This, in effect, defines a part from an economic standpoint since it contains setup cost, unit cost and the inventory carrying cost. Since this is a new concept, there has been no generally acceptable name developed for the expression, although "quantity factor" and "part-period" seem to be fairly well established. What this factor boils down to is the number of parts which if carried in inventory for one period would result in an inventory charge equal to the setup cost. In the previous examples S/IC would be \$40.00/.005 × \$1.00 = 8000, meaning that 8000 parts carried for one week (or 4000 parts for 2 weeks, etc.) would result in an inventory charge equal to the setup charge. This, I suspect, will become a very useful number in various inventory control applications.

To get back to the formulas, both expressions are related to S/IC. However, the weighting the requirements is completely reverse. Assume four time periods ($n=4$) in order to make the two expressions easier to read:

Least unit cost – $4R_1 + 3R_2 + 2R_3 + 1R_4$

Least total cost – $0R_1 + 1R_2 + 2R_3 + 3R_4$

The least unit cost puts a higher weight on the first requirement which is held in stock for much shorter time period than is the requirement for period five. This is not at all logical from a cost of inventory standpoint. On the other hand the weightings for the least total cost do seem to be more logical.

Another, probably even more disturbing, thing about the least unit cost formula is that it says that if the total at period n is less than S/IC, then the unit cost at n + 1 will be less regardless of quantity or inventory charges. This helps to understand why some of the orders developed by the least unit cost method are illogical as they were in Figures 1 and 2. As long as unit cost decreases it will order regardless of what it does to total cost.

In conclusion, the least unit cost method, in spite of its extremely attractive name and easily understood logic, actually does not develop orders which result in a low over-all cost. On the other hand, mathematical analysis and extensive comparative tests show that the least total cost system results in substantially lower costs of both inventory and setup. Although it is a little more complex in concept, it is equally simple to administer and use, and it certainly gives better results.

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APPENDIX

Derivation of Formulas

1. *Formula for Least Unit Cost*

$$\text{Unit cost} = \frac{\text{Setup Cost} + \text{Inventory Cost}}{\text{Quantity}}$$

Setup cost $= S$

Inventory Cost $=$ Requirement qty $\times$ weeks in Inventory $\times$ Cost of part $\times$ Inventory carrying cost.

Assuming that the first requirement is used as soon as it is received, the weeks in inventory would be zero. Then

$0R_1IC$ = cost of inventory for the first requirement

$1R_2IC$ = cost of inventory for the second requirement

$(n-1)R_nIC$ = cost of inventory for the n^{th} requirement

$nR_{n+1}IC$ = cost of inventory for the $n+1$ requirment

The total cost of inventory would be

$$0R_1IC + 1R_2IC + 2R_3IC = \ldots + (n-2)R_{n-1}IC + (n-1)R_nIC$$

or

$$[0R_1 + 1R_2 + 2R_3 + \ldots + (n-2)R_{n-1} + (n-1)R_n]IC$$

let $R_I = 0R_1 + 1R_2 + 2R_3 + \ldots + (n-2)R_{n-1} + (n-1)R_n$

Quantity is the sum of the requirements,

$$R_T = R_1 + R_2 + R_3 + \ldots + R_{n-1} + R_n$$

$$\text{Thus unit cost at } n = \frac{S + R_IIC}{R_T}$$

$$\text{Unit cost at } n+1 = \frac{S + R_IIC + nR_{n+1}IC}{R_T + R_{n+1}}$$

Order R_{n+1} if unit cost is less than at R_n

Order R_{n+1} if

$$\frac{S + R_IIC + nR_{n+1}IC}{R_T + R_{n+1}} < \frac{S + R_IIC}{R_T}$$

This simplifies to

$$nR_TIC < S + R_IIC$$

$$nR_TIC - R_IIC < S$$

$$nR_T - R_I < \frac{S}{IC}$$

Substituting for R_T

$$nR_T = n(R_1 + R_2 + R_3 + \ldots + R_{n-1} + R_n)$$

$$nR_T = nR_1 + nR_2 + nR_3 + \ldots + nR_{n-1} + nR_n$$

$$R_I = 0R_1 + 1R_2 + 2R_3 + \ldots + (n-2)R_{n-1} + (n-1)R_n$$

$$nR_T - R_I = nR_1 + (n-1)R_2 + (n-2)R_3 + \ldots + 2R_{n-1} + 1R_n < \frac{S}{IC}$$

Order R_{n+1} if

$$nR_1 + (n-1)R_2 + (n-2)R_3 + \ldots + 2R_{n-1} + 1R_n < \frac{S}{IC}$$

2. *Least Total Cost*

This balances the cost of inventory with cost of setup.

Cost of Inv. = Cost of setup

$$R_IIC = S$$

$$R_I = \frac{S}{IC}$$

$$R_I = 0R_1 + 1R_2 + 2R_3 + \ldots + (n-2)R_{n-1} + (n-1)R_n = \frac{S}{IC}$$

About the author —

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NET CHANGE MATERIAL REQUIREMENTS PLANNING *

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In the summer of 1971, APICS published a special report entitled MATERIAL REQUIREMENTS PLANNING BY COMPUTER. This publication, which is based on the proceedings of a workshop attended by people from a number of companies that use Material Requirements Planning, contains the following statement:

> "The more experienced companies at this workshop used a Net Change system and felt strongly that Net Change was the only way to go . . ."

I completely agree with this conclusion. My view may be a bit biased, because I had a hand in the design and implementation, in 1961, of the prototype system of which the referenced systems are an outgrowth.

The Significance of Net Change

The knowledge of the principles and techniques of Net Change Material Requirements Planning has thus far resided mostly with actual users, as very little has been written or publicly expounded on the subject. To make the information more widely available is why I have selected this topic for my 1971 APICS Conference presentation.

The production and inventory control professional should know that there is more than one approach to Material Requirements Planning, and should understand the advantages and drawbacks of Net Change. He must know when and where the Net Change approach should be considered, because he may be called upon to decide and make the choice at the time his company commits itself to implement a Material Requirements Planning system. He should also understand under what circumstances it becomes desirable to switch from a conventional, regenerative Material Requirements Planning system to a Net Change system.

The Question of Replanning Frequency

I recall a meeting, in January, 1961, at the large tractor works of the J. I. Case Company in Racine, Wisconsin. That day, I joined several people with whom I was then associated at Case to work out the basic specs for a new Material Requirements Planning system that was to be implemented on the company's first computer.

Among other features of the proposed system, we needed to specify the *frequency* of the requirements explosion, trying to decide between a monthly, semi-monthly, or weekly cycle. In the dynamic environment of tractor manufacture, a high frequency of replanning was obviously desirable, but the trade-off lay in the scope of the requirements explosion job and the volume of printed output generated during each cycle. The problem boiled down to the question: "How often is it *practical* to re-explode and replan requirements?"

To arrive at the answer, we posed a somewhat different question: "How often would a system *ideal* for our business re-explode and replan requirements?" After some debate, the consensus of the group was that ideally, replanning should be taking place continuously, i.e., should be entirely non-cyclical.

An Alternative to Schedule Regeneration

It was not clear, at first, how this could be achieved with Material Requirements Planning, as the conventional, and traditional, approach to the job is based on so-called schedule regeneration and on sequential processing techniques. Regeneration is a batch processing method which, by definition, must be tied to some *periodic* frequency.

Further study and analysis revealed, however, that a non-periodic, non-batch Material Requirements Planning system could, in fact, be implemented, provided the computer had random-access file storage. In 1961, some IBM computer models were already being offered with disk storage as an alternative to magnetic tape storage.

With the capability of random access to file records, sequential processing was no longer mandatory (though, of course, still possible). This meant that periodic batch data processing methods, heretofore dictated by the economics of sequential processing, could be abandoned for applications where they had been a drawback.

If a Material Requirements Planning system were designed accordingly, the processing of the pertinent data could proceed in a continuous mode, in contrast to some arbitrary frequency of a re-planning cycle. All inventory records, *including requirements planning data*, could be kept up to date (up to the minute) at all times.

The group at J. I. Case proceeded to design such a system from scratch. It was called Net Change and became operational in 1962. The original Case system is the predecessor, and has served as the prototype for the design of, Net Change Material Requirements Planning systems since implemented by several other manufacturing companies.

*Thi[illegible] [illegible]ticle is based on the author's speech at the 14th International Conference of APICS, Nove[illegible] [illegible]1, 1971, St. Louis, Missouri

The Regenerative Method

The best way to bring out the salient characteristics of Net Change Material Requirements Planning is by using its conventional counterpart as a point of departure. The regular, prevalent approach to Material Requirements Planning is based on *schedule regeneration*. Under this approach, the entire master production schedule, which constitutes the prime input to a Material Requirements Planning system, is "exploded", or broken down, into detailed requirements for every individual item and existing inventories (on hand plus on order) are, in effect, reallocated in a level-by-level process.

Under the regenerative approach

1. Every end item requirement stated on the master production schedule must be exploded
2. Every (active) bill of material must be retrieved
3. Every (active) inventory item record must be recalculated
4. Voluminous output is generated

Schedule regeneration is always a big job, even on a big computer. Inherent to the regenerative approach is the task of massive data handling which

1. Entails a delay in obtaining the results of the requirements planning run
2. Dictates that the job be done periodically, i.e., at economically reasonable intervals

This causes the system to be out of date, in some degree, *at all times.*

How important these disadvantages are in a given case depends on both the *environment* in which the system must operate, and the *uses* to which it is being put. Let's look at these one at a time.

In a dynamic, or volatile, environment the situation is in a continuous state of change. There are frequent changes in the master production schedule. Customer demand fluctuates and orders are being changed, perhaps day by day. Interplant orders arrive erratically. There are rush service part orders. There is scrap. There is a constant stream of engineering changes. All of this means that requirements for individual inventory items, and their timing, are subject to rapid change.

In a volatile environment of this kind there is a strong need for timeliness of response to change, but a regenerative Material Requirements Planning system can replan only periodically -- at best, probably once a week. Its reflexes are relatively sluggish, because it is not really geared to the rhythm of the operation it is intended to support.

A Question of Use

In a more stable environment, a regenerative Material Requirements Planning system may function satisfactorily, as far as *material requirements* are concerned. But Material Requirements Planning is more than just an inventory system. If it is to be put to its full and proper use, it a[illegible]ly functions on three distinct levels:

1. Planning and controlling inventories
2. Providing the basis (through its "planned order" schedules) for planning capacities
3. Maintaining priorities of open shop orders (and purchase orders) up to date and valid

The shop priority control function represents a vitally important capability of a time-phased Material Requirements Planning system. Oliver Wight has repeatedly been stressing this point in his recent writings and talks. At present, this is still ill-understood and consequently little used. Every Material Requirements Planning system has an inherent, built-in capability to reevaluate and revise all open order due dates. It is these due dates that form the basis of any sound method of establishing relative priorities of shop orders, and of operation sequencing.

If these priorities are to be kept valid, however, the shop order due dates on which they are based must obviously be maintained up to date. If we want shop priorities valid at all times we must have order due dates that are up to date at all times.

A Material Requirements Planning system that replans in infrequent cycles can obviously do no better than to generate order due dates that are *only periodically up to date*. Unless the environment is exceptionally stable, it is hard to see how shop priorities can be kept constantly valid by such a system. But that is just the point. If the formal system cannot do the job, the informal system must, and will, take over.

The informal system of assembly shortage lists and "hot order" expediting can exist side by side with an apparently sophisticated computer system. The informal system is, of course, devised by operating people to *overcome the deficiencies* of the formal system. Shop order due dates need to be revised on short notice, so the expediters revise them then and there, as required. It is fortunate that they do, because the business could not afford to wait for the next computer run, days or perhaps weeks away.

Specs for a Material Requirements Planning System

With Material Requirements Planning, the frequency of replanning is a critical variable in the *use* of the system. It is also a critical parameter in the *design* of the system, because the regenerative approach makes it impractical to replan at a frequency higher than about once per week.

When the specs for a Material Requirements Planning system are being defined, the frequency of replanning should be specified by the user, i.e., by a manufacturing executive or by the Production Control Manager. This frequency should be geared to the particular environment in which the Material equirements Planning system is to operate, and to the uses that are to be ade of it, as we discussed.

In deciding on the required frequency of replanning, the user should be ee of constraints and should be able to specify the frequency that the usinesss calls for -- including a daily cycle, or even *continuous* replanning. o settle for less than what is really needed will ensure, right at the outset, at the proposed Material Requirements Planning system will have its fectiveness impaired.

To be able to replan material requirements at a high frequency, we must olve the problem of data processing economics, i.e., the scope of the eplanning job, its duration, the volume of its output, and the delay inherent 1 any massive batch-processing run.

In other words, we need a non-regenerative approach to Material Requirements Planning. An approach that will minimize the number of ventory records and bills of material that must be accessed during the eplanning process. An approach that will limit the volume of (automatically enerated) output to notices of *currently* required action.

A Material Requirements Planning system designed on the Net Change oncept is the answer here, as it solves every one of the just-mentioned roblems.

Characteristics of a Net Change System

Such a system can be implemented for either of two modes of use:

1. High frequency replanning (on, typically, a *daily batch* basis)
2. *Continuous*, or on-line, replanning (a "transaction-driven" system)

Prevailing current practice, in companies that have implemented a Net Change Material Requirements Planning system, is daily batch for transaction processing, with continuous on-line inquiry into the part No. file.

Aside from current practice, however, it should be noted that the system's design allows it to become transaction-driven whenever the user deems this mode desirable. On-line transaction entry is a matter of terminal and software arrangements external to the system itself. The system is *independent* of these. The system, in any case, is up to date as of the last transaction processed. It can be the more up to date the less delay there is in bringing transactions to it.

The *logic* of planning and time-phasing material requirements is essentially the same for both conventional and Net Change systems, except for

1. The treatment of the master production schedule
2. A *partial explosion* of requirements

The Net Change Concept

Under the Net Change approach,

1. The mas' roduction schedule is viewed as *one plan in continuous existence*, rather than as successive versions or issues of the plan
2. The master production schedule can be updated (as a result of an authorized change) *at any time*, by adding or subtracting the net difference from its previous status
3. Periodic issues of a new schedule are treated the same way, in effect as a special case of updating for change

The idea may become clearer if the schedule is envisioned to resemble a Chinese scroll which is continually being unwound, analogous to passage of time. The contents of each "bucket" in the master production schedule grid is either zero or some positive value. In concept, the schedule extends indefinitely into the future, all buckets beyond the planning horizon having zero contents. Passage of time brings segments of the future within the planning horizon, at which time their contents are normally changed (via the issue of a new schedule) from zero to some positive value.

Because the master production schedule is updated or changed (the two are equivalent under the Net Change concept) by means of addition or subtraction of the net difference relative to its previous status, the task of replanning is minimized.*

Thus if a 6-month schedule looked in March as in Fig. 1, and in April as in Fig. 2, the difference from previous status would net out as shown in Fig. 3.

This is the *net change* that would be processed (exploded) by the Material Requirements Planning system on whatever day the new schedule is approved. In our example, out of a total of 18 master production schedule "buckets" within the planning horizon, 15 remain unaffected. It should also be noted that the schedule for product B continues unchanged. In this case, the data processing job on a Net Change basis would be only a fraction of the job that a conventional Material Requirements Planning system would have to perform. This is so because under the schedule-regeneration approach, the contents of all 18 "buckets" would be input to the Material Requirements Planning system, and all inventory records as well as bills of material related to products A, B, and C would have to be accessed and processed.

It is important to point out also that if, in our example, the need to reduce the August quantity of product A had been recognized at some time in March, it could have been processed by a Net Change system at that time, without waiting for the next (April) issue of the schedule. In that case, the net impact of the April schedule, as far as product A is concerned, would be limited to the addition of 40 for September.

*This treatment of the master production schedule was pioneered by American Bosch in Springfield, Mass. in a bi-weekly batch Material Requirements Planning system implemented in 1959

PLANNING HORIZON

PRODUCT	MAR	APR	MAY	JUN	JUL	AUG
A	80	70	30	0	0	50
B	100	60	80	100	60	60
C	15	0	10	15	0	10

Figure 1

PRODUCT	APR	MAY	JUN	JUL	AUG	SEP
A	70	30	0	0	35	40
B	60	80	100	60	60	0
C	0	10	15	0	10	15

Figure 2

PRODUCT	APR	MAY	JUN	JUL	AUG	SEP
A					−15	+40
B						
C						+15

Figure 3

Partial Explosion

With a conventional Material Requirements Planning system, *all* requirements are exploded in one batch processing run, as the master production schedule is periodically being "regenerated". During this run, the net requirements for each inventory item are being recalculated and its "planned order" schedule is recreated. The entire process is carried out in level-by-level fashion, starting with the highest (end item) product level and progressing down to the lowest (purchased material) level. All items on a given level are processed before the next lower level is addressed.

With a Net Change Material Requirements Planning system, only a *partial explosion* is carried out. Only those inventory records that are actually affected by a given net change are reprocessed, and only those bills of material that are pertinent to these records are retrieved.

The partial explosion is the key to the practicability of the Net Change concept, as it minimizes the scope of the Material Requirements Planning job at any one time, and thus permits a high frequency of replanning. Because the explosion is only partial, it automatically limits the volume of the resulting printed output. This, of course, is also an important consideration.

Continuous Net Change

Partial explosion is a characteristic of any Net Change Material Requirements Planning implementation, whether the system is operated in a daily batch mode or in a *continuous* mode. A partial explosion is triggered not just by changes to the master production schedule but also by certain inventory transactions, such as scrap or physical inventory adjustment entries. In fact, any transaction that alters the "planned order" schedule of an item in any way, causes an explosion to (revision of requirements for) its component lower-level items.

A continuous, non-cyclical Net Change Material Requirements Planning system, such as the original J. I. Case system mentioned earlier, has additional special characteristics. The updating process triggered by a given transaction is completely carried out before the next transaction is processed. This means that in those cases where a change in status of one inventory item affects other, lower level items, all of the respective records (perhaps on several successive levels) will be updated as a result of a single transaction entry.

Thus the individual partial explosions take place as part of the transaction updating process which goes on in a continuous fashion. In contrast with a batch-oriented system, where the explosion proceeds in *horizontal* stages (level by level), in a continuous Net Change system the intermittent explosions progress, as it were, *vertically* down the product structure.

Any transaction on any inventory item is fully processed at the time it is presented to the system. This means that transactions may be entered in *random sequence* at *random times.*

Net Change Outputs

As mentioned earlier, the volume of automatically generated output (as distinct from output generated in response to inquiry) under Net Change is in any case limited to only those items affected by a partial explosion. This can be further restricted by suppressing output related to items that require no *current* action.

This is really the only practical way to handle outputs with continuous Net Change Material Requirements Planning. Automatic outputs are generally limited to situations calling for immediate action, such as placing, canceling, or rescheduling an order. Only information for imminent action is being displayed or printed out. Information for action *planned* for the future (tomorrow, next week) is being withheld from the user until it matures and actually needs to be acted on.

Advantages of Net Change

A Net Change Material Requirements Planning system is superior to its conventional counterpart, in several respects. The Net Change approach enables the system to

1. Minimize the requirements planning (explosion) job at schedule release time
2. Process schedule changes occurring between release cycles
3. Be independent of the *timing* of both releases and changes
4. Be continually up to date
5. Generate non-delay outputs (thus communicating the need for inventory management action at the earliest time possible)

From the user's point of view, the essential characteristic of a Net Change system is its *reactiveness*, its unique capability of timely response to change.

"Drawbacks" of Net Change Systems

Negative aspects of Net Change Material Requirements Planning, and the usual targets of skepticism can be categorized as follows:

1. The relative processing inefficiency of Net Change
2. The "nervousness" of the system
3. Reduced self-purging capability, and the consequent need for stricter external disciplines

Let me briefly deal with each of these. It is a fact that from the data processing point of view, Net Change is less efficient, and therefore more costly, primarily due to its characteristic of multiple access to inventory records, in both the straight transaction update and explosion modes.

But this cannot be considered a valid argument against Net Change. Any data processing method that does not utilize sequential processing techniques is, by definition, relatively inefficient.

In Net Change Material Requirements Planning, the emphasis is on *requirements planning efficiency*, and *data processing efficiency* is deliberately sacrificed to this end. In the development of Material Requirements Planning systems, like in many other business computer applications, there is a trade-off between data processing efficiency and the efficiency of the business function the system is intended to support. In these cases, data processing efficiency should never be a primary objective, but should be subordinated to the larger goal of improving the effectiveness of the *business*.

The second type of criticism refers to the "nervousness" of a Net Change system. Since the system is continuously updating itself, it is also continuously replanning, and thus revising, order action. This might appear as causing a stream of constant revisions of open orders, both in the shop and those previously placed with outside suppliers. That need not be so, however, and in practice it does not happen.

This type of criticism neglects to draw a distinction between

1. The system being informed, up to the minute
2. The frequency of action taken on the basis of the information

The latter can obviously be decided on (based on practical considerations), independently of the former. A deliberate withholding of user action in the full knowledge of current facts is preferable to a lack of action caused by ignorance of these facts.

The "nervousness" on the level of *planning* is a virtue, not a drawback, of a Net Change Material Requirements Planning system. The "nervousness" on the level of *reaction* can, and should, be dampened. Let me discuss the timing of action separately, in more detail, a little later on. Not every change in inventory status calls for reaction, anyway.

Many minor changes of the type that would otherwise require action are absorbed by inventory surpluses that exist as a result of previous inventory management decisions. These surpluses are created by safety stock, safety lead time, and temporary excesses in inventory due to lot sizing, engineering changes, reduced requirements, forecast error, overshipments, overruns, and premature deliveries by suppliers.

The system constantly strives to use up such temporarily excessive inventories as early as possible, through the net requirements planning process. Inventory excesses are thus automatically prevented from accumulating, but under normal conditions they exist, in some measure, at any point in time.

Besides relying on normal inventory surpluses to absorb minor changes, "dampers" on such changes can, if desired, be programmed into the system. The user can specify limits within which changes in both timing and order quantity cannot be made by the system. If such change-dampening rules are made to apply to "planned orders" as well as to open orders, many partial explosions of trivial nature will be suppressed, precluding further changes in lower-level component records.

The critic of a "nervous" system argues, in effect, that it is better for an inventory management system to be out of date. Such an argument is simply unacceptable. Keeping the system intentionally ignorant of current facts, to whatever degree and for whatever length of time, can never be an advantage.

The third type of criticism relates to a need for increased discipline under a Net Change Material Requirements Planning system. From the practical point of view, it must be conceded that this is indeed a disadvantage.

With the conventional regenerative system, the old plan is literally thrown away every time a new version of the master production schedule is authorized. The job of exploding and planning requirements then proceeds from scratch. This has the advantage of throwing away old errors, plus data hat became invalid due to change, along with the old plan.

The opposite is true, of course, with the Net Change approach. The old plan is retained and merely modified, updated. Old errors never fade away, and changes in the bill of material, in lead times, and in other parameters of the system must be methodically incorporated, as they occur. Furthermore, the planned (forecast) requirement data at the highest assembly level that is reflected in the system must be conscientiously *reconciled* with actual past requirements. Otherwise the discrepancies between "planned" and "actual" are carried forward and their cumulative effect will gradually render the system ineffective.

Net Change Material Requirements Planning is a *continuous* system that must be *continuously* maintained. It presupposes that high data integrity can be sustained, in both transaction entries and file records. Companies that use Net Change Material Requirements Planning maintain a stand-by program for requirements regeneration, to be substituted for the Net Change program if and when the system's records accumulate too many errors. The stand-by program is then run once, to purge the system by regenerating all requirements and "planned orders". In actual practice, operational Net Change systems are being thus purged once or twice per year.

Of the three "drawbacks" of Net Change Material Requirements Planning, the first two prove to be nonexistent upon closer examination. The third one constitutes the only objection that has any validity at all.

A company that is unable to impose, and maintain, the required degree of procedural discipline will not be happy with a Net Change Material Requirements Planning system. For such a system to function with full success requires, to quote George Plossl*, "a management policy intolerant of errors. A zero-defects approach is necessary . . . *a climate of accuracy*". Unless and until management creates such a climate, the system simply cannot properly function.

The Timing of Action Under Net Change

Prompt reaction to changes in requirements or coverage is generally called for when requirements *increase*, or when the timing of planned performance *advances*. For the opposite type of change, a delay or lack of reaction can be tolerated. Changes can occur every minute of the day as a result of updating inventory, order, and requirements data. Stock status is not significantly affected by most of the updating transactions -- for example, a planned component issue against a previously released order, or a stock receipt. Stock status re-evaluation is, however, called for by some transactions, such as:

1. Unscheduled stock issues
2. Scrap
3. Physical inventory adjustments (short counts)
4. Miscellaneous demand exceeding forecast
5. Entry of an engineering change

Many changes may occur in the same inventory record on the same day, in which case orders would have to be replanned several times that day, even though the changes may have a mutually canceling effect.

The user's reaction to change can be *de-coupled* from the rate at which individual changes occur and are processed by the system. The most common method of dampening reaction to change is simply to *delay* such reaction. In practice, this takes the form of periodic action cycles on the part of the inventory planner. He does not react to the continuous stream of individual changes, but lets them accumulate for a period of, say, one day or longer.

The computer can be programmed to provide output of action requests on a cyclical basis. Some of these action messages would typically be generated, in a batch, once a day. Most requests for normal order action (release of shop orders and purchase requisitions) belong in this category.

Different action cycles apply to various types of action, depending on its *purpose*. Thus due dates for all open shop orders may be reevaluated once per shift, so as to maintain the validity of shop priorities. For certain types of messages (premature supplier deliveries, for example), a weekly cycle would be sufficient.

Other types of messages, however, should be generated without *any* delay, because corrective action time is critical. For example, an open purchase order may become a candidate for cancellation, as a result of changed requirements. A 24-hour delay in reacting to the new situation can make the difference between being or not being able to cancel. Other examples of situations that call for reaction without delay are excessive scrap, requirements falling into the past caused by a change in the status of a higher-level inventory item, a significant downward adjustment of inventory following a physical count, etc.

When major changes in the master production schedule are being processed, or following regular periodic issues of the schedule, all action-request output should be suppressed until the entire net change has been completely processed by the system. That type of change may affect thousands of records, and the status of an inventory item may change several times during the processing of such a change.

It should be kept in mind that planning cycles and action cycles are established on a more or less arbitrary basis. Delaying action on available information does dampen reaction to change, but delay obviously cannot be prolonged indefinitely. Under any action cycle, once delay is terminated,

*Designing and Implementing a Material Requirements Planning System. APICS International Conference, Cincinnati, 10/8/70.

subsequent changes can still invalidate the action taken. As a general rule, it is better to act with less delay under a system capable of frequent -- or continuous -- replanning, reevaluation and revision of previous action, than to tolerate unresponsiveness by operating on long planning and action cycles.

Net Change Material Requirements Planning offers a range of responses, from zero-delay to weekly and monthly cycles. The relative promptness of reaction to change should be a function of the *type* of change in question.

The Future of Net Change

In my opinion, the future belongs to Net Change Material Requirements Planning. Earlier, I pointed out its several advantages and its superiority over conventional, regenerative Material Requirements Planning. Superiority on the *practical level* of use is what counts, of course.

On the *technical level*, the *continuous* variety of Net Change Material Requirements Planning represents an advanced systems approach in that the logic of the application anticipates, and is compatible with, the trend in information processing technology. This type of Net Change system can be implemented in any one of several degrees of sophistication in input/output flow arrangements. The system's central architecutre remains unaffected by any of these (external) arrangements, and by the technology of input/output devices used.

Continuous Net Change Material Requirements Planning can be implemented as a strictly card-oriented system, such as the prototype Case system was, with manual data collection, and output limited to cards and printout. Today's Net Change systems are typically supported by card-output data collection, and may have visual display units on-line, in addition to printers.

The system can be operated in any of these ways, and in others. It is ready to be operated as a communications-oriented, on-line, real-time system of the future. It is ready, whenever that future arrives. The Net Change Material Requirements Planning system itself will require no change -- it is *already there*.

* * * * *

Historical Note

In 1961, at the J. I. Case Company tractor plant in Racine, Wisconsin, a project group under my direction designed and installed the first *continuous* Net Change Material Requirements Planning system. The original system was implemented on an IBM 305 RAMAC with 15 million characters of disk file capacity. This prototype version of a Net Change system was relatively crude. Inventory records of 500 character positions corresponded to one RAMAC disk track sector. Each such record contained three 1-week "buckets" plus seven 4-week "buckets." There were only two types of output: an action ticket which included the image of the entire record (generated automatically, or in response to inquiry, at random times) and a weekly control report. The system covered about 20,000 active part No's., including 4,000 assemblies with up to seven assembly levels. As IBM had no programming support for a material requirements planning application at that time, the J. I. Case programmer team had to write their own equivalent of the Bill of Material Processor, in addition to the application programs.

The development and programming took ten months following a two-month feasibility study. The project team expended approximately six man-years in the development/programming phase. This is exclusive of system-related work performed by user personnel.

The prototype system was implemented on a stand-alone basis, with the computer fully dedicated to the Net Change Requirements Planning application. The system was subsequently re-implemented on an IBM 1410 with a 1301 disk file, and eventually converted to an IBM System/360 Model 50.

My closest collaborators on the project are listed here in alphabetical order: A. R. Brani (Case), I. A. Chobanian (Case), H. D. Jones (Case), T. L. Musial (IBM), E. F. Roeseler (Case). Company affiliations are as of that time. I held overall responsibility for the system, in my capacity, at that time, of Director of Production Control for the J. I. Case Company.

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He received his doctorate in law and economics from Charles University, Prague, in 1948 and his M. B. A. from the University of Chicago in 1951. Prior to joining IBM in 1962, he served as Director of Production Control of J.I. Case Company.

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STRUCTURING THE BILL OF MATERIAL FOR MRP

Joseph A. Orlicky
George W. Plossl
Oliver W. Wight

INTRODUCTION

An important distinction between Order Point systems and Material Requirements Planning systems lies in the fact that the order point/order quantity approach is *part based* whereas MRP is *product-oriented*. Order Point views each inventory item independently of all the others, whereas MRP looks at the product and the relationships of its components, using bills of material as the basis for planning.

MRP puts the bill of material to a whole new use. Under MRP, the bill acquires a new function, in addition to serving as part of the product specs. It becomes a framework on which the whole planning system hangs.

Often, however, the bill of material furnished by the engineering department is not necessarily *usable* for material requirements planning. As a key input to an MRP system, the bill of material must be accurate and up to date if MRP outputs are to be valid. But in addition it must be unambiguous and so structured as to *lend* itself to MRP. The mere existence of a bill of material is no guarantee that MRP will actually work.

To understand the reason for this, we must remember that the bill of material is basically an engineering document. Historically, the function of the bill of material has been to define the product from the design point of view and from the design point of view only. But now, because we want to use the bill of material for purposes of material planning, we must re-define the product from the manufacturing and planning point of view. Proper product definition is crucial to a planning system such as MRP, which directly depends on it—*unlike* an order point system.

People usually think of bills of material, and of MRP as being applicable only in hard goods manufacturing. But businesses that *mix* component materials, *sew* them together, *package* them, etc., can also use material requirements planning to advantage. Companies in the garment industry, pharmaceutical houses, batch chemical manufacturers, and others, all have bills of material except they call them by different names—material lists, formulations, specifications, etc.

With MRP, the prime input to the whole system is the master production schedule. The product must be defined in such a way as to make it possible to put a valid master schedule together in terms of bill of material numbers; i.e., assembly numbers. If the overall plan of production—and that is what the master schedule is—cannot be stated in terms of bills of material, it is not possible to do material requirements planning successfully.

The master schedule and the structure of the bill of material must be thought of together, when an MRP system is being developed. The bills of material and the master schedule must *fit together* like lock and key. If these are not compatible, nothing turns. Neither is there any guarantee that an MRP system can function properly just because the bill may already have been organized and loaded onto a computer file under a *Bill of Material Processor* program. This type of software will load practically anything onto a disc file, including straight engineering parts lists—which are not much good for purposes of material requirements planning. The functions of a bill processor are merely to organize, maintain, and retrieve bill of material data. A Bill of Material Processor is not designed to *structure* the bill. It assumes that the bill is already properly structured to serve the user's needs.

The intent of the discussion that follows is to clarify the subject of bill of material *structuring*, so that it will not be confused with bill of material *file organization* under a bill processor.

In most instances, companies planning to implement MRP will be wise to review their bills of material, to determine whether certain changes in the structure of this file data may have to be made, and of what kind. In reviewing the bill for this purpose, the following seven-point checklist will help in spotting its structural deficiencies:

1. *The bill should lend itself to the forecasting of optional product features.* This capability is essential for purposes of material requirements planning.
2. *The bill should permit the master schedule to be stated in the fewest possible number of end items.* These end items will be products or major assemblies, as the case may be, but in either case they must be stated in terms of bill of material numbers.
3. *The bill should lend itself to the planning of subassembly priorities.* Orders for subassemblies have to be released at the right time, and with valid due dates.
4. *The bill should permit easy order entry.* It should be possible to take a customer order that describes the product either in terms of a model number, or as a configuration of optional features, and translate it into the language that the MRP system understands: bill of material numbers.
5. *The bill should be usable for purposes of final assembly scheduling.* Apart from MRP, the final assembly scheduling system needs to know, specifically, which assemblies (assembly numbers) are required to build individual units of the end product.
6. *The bill should provide the basis for product costing.*

7. *The bill should lend itself to efficient computer file storage and file maintenance.*

When, in a given case, these yardsticks are applied to the existing bill of material, it will usually be found that some, but not all, of the above requirements can be satisfied. If that is the case, changes in bill of material structure are called for. This can and should be done. While the bill still must serve its primary purpose of providing product specifications, it should not be regarded as a sacrosanct document that must not be tampered with. The bill may have to be modified, or *restructured*, as required for purposes of material requirements planning. This can be done without affecting the integrity of the specs.

The severity of the bill of material structure problem varies from company to company, depending on the complexity of product and nature of the business. The term "bill of material structuring" covers a variety of *types* of changes to the bill, and several different techniques for effecting these changes.

The topics that make up the subject of bill of material structuring, as reviewed in this article, can be categorized as follows:

1. *Assignment of identities*
   - (a) Elimination of ambiguity
   - (b) Levels of manufacture
2. *Modular bill of material*
   - (a) Disentangling product option combinations
   - (b) Segregating common from unique parts.
3. *Pseudo-bills of material*

IDENTIFICATION OF MATERIALS AND THEIR RELATIONSHIPS

There are several principles involved here. First, the requirement that each individual item of inventory covered by the MRP system be uniquely identified. This includes raw materials and subassemblies.

The assignment of subassembly identities tends to be somewhat arbitrary. Between the design engineer, the industrial engineer, the cost accountant and the inventory planner, each might prefer to assign them differently. The question is: When do unique subassembly numbers have to be assigned? In reality, it is not the design of the product but the way it is being manufactured; i.e., assembled, that dictates the assignment of subassembly identities.

The unit of work, or task, is the key here. If a number of components are assembled at a bench and then are forwarded as a completed task, to storage or to another bench for further assembly, a subassembly number is required so that orders for these subassemblies can be generated and their priorities planned. An MRP system will do this, but only for items with individual identities.

Some engineering departments are stingy in assigning new part numbers, and we often see the classic example of this in a raw casting that has the same part number as the finished casting. This may suit the engineer, but it is difficult to see how an automated inventory system such as MRP is supposed to distinguish between the two types of items that must be planned and controlled separately.

The second requirement is that an identifying number define the *contents* of the item uniquely, unambiguously. Thus the same subassembly number must not be used to define two or more different sets of components. This sometimes happens when the original design of a product subsequently becomes subject to variation. Instead of creating a new bill with its own unique identity, the old one is specified with instructons to substitute, remove, and add certain components. This shortcut method, called "add and delete," represents a vulnerable procedure, undesirable for MRP. We will come back to it in a later example.

The third requirement is that the bill of material should reflect the way material flows in and out of stock. "Stock" here does not necessarily mean "stockroom" but rather a *state of completion*. Thus when a piece part is finished or a subassembly is completed, it is considered to be "on hand"; i.e., in stock, until withdrawn and associated with an order for a higher level item as its component. An MRP system is constructed in such a way that it assumes that each inventory item flows into and out of stock at its respective level in the product structure. MRP also assumes that the bill of material accurately reflects this flow.

Thus the bill of material is expected to specify not only the *composition* of a product but also the *process stages* in that product's manufacture. The bill must define the product structure, in terms of so-called *levels of manufacture*, each of which represents the completion of a step in the buildup of the product.

A schematic representation of product structure is shown in Figure 1. The structure defines the relationship among the various items that make up the product in terms of levels, as well as the parent item/component item relationships. These things are vital for material requirements planning because they establish, in conjunction with lead times, the precise *timing* of requirements, order releases, and order priorities.

The product represented by Figure 1 has four levels of manufacture. The end product is designated, by convention, as being at level zero, its immediate components as being at level one, etc. The parent/component relationships depicted in the example indicate that "A" is the parent of component "C" (also of "B" and "1"). Item "C," in turn, is the parent of component "3," etc. Thus "A" is the only item that is not also a component.

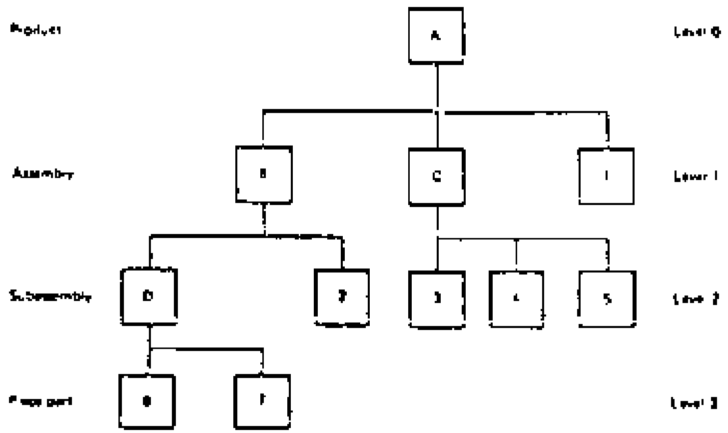

Figure 1.

Items "B," "C" and "D" are both parents (of their components at the next lower level) and components (of their parent items at the next higher level). Items "1" through "7" are components but never parents.

This would be true if all of the piece parts were purchased. If item "6," however, is manufactured from raw material "X," then it becomes a parent in relationship to this component material. Thus the distinction between parent item and component item appears not only in assembly but also in the conversion of material for a single part from one stage of manufacture to another.

This also applies to semi-finished items that are stocked (in the sense described earlier) and that are to be controlled by the MRP system. The raw material, the semi-finished item, and the finished item must be uniquely identified; i.e., must have different part numbers.

People are sometimes reluctant to assign different identities to semi-finished and finished items, where the conversion to the finished stage is of minor nature. A good example is a die casting that is machined and then painted one of four different colors, as shown in Figure 2. The four varieties of painted casting will have to be assigned separate identities if they are to be ordered, and their order priorities planned, by the MRP system.

This is an example of a situation where item identity (of the painted casting) would normally not exist, but would have to be established prerequisite to MRP, because otherwise such items would fall outside the scope of the system and loss of control would result.

Another example of an item identity problem that is almost the opposite is the transient subassembly, sometimes called a "blow-through" or "phantom." Assemblies of this type never see a stockroom, because they are immediately consumed in the assembly of their parent items. An example of this is a subassembly built on a feeder line that flows directly into the main assembly line. Here the subassembly normally carries a separate identity.

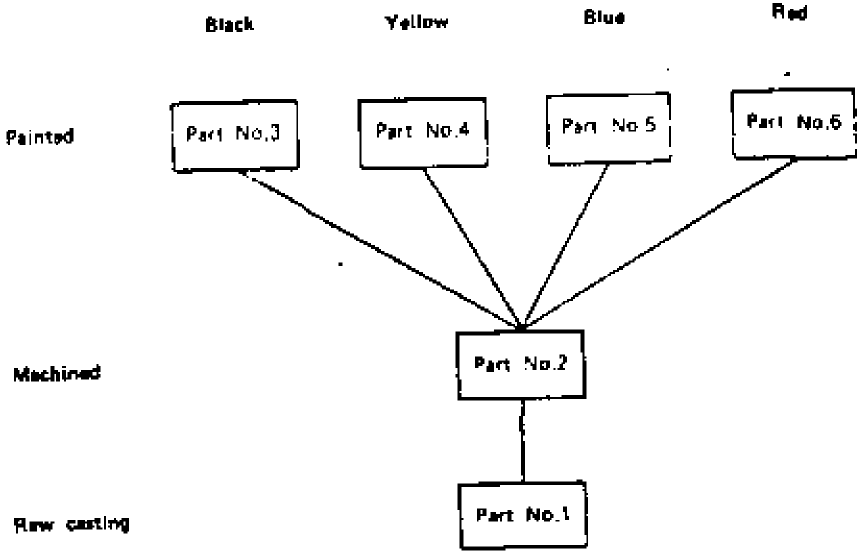

Figure 2.

Because it is recognized in the bill of material, the MRP system would treat it the same as any other subassembly.

This may be undesirable, because if this kind of item is to be planned under an MRP system, we must remember that the logic of MRP assumes that each component item goes in and out of stock. That is the way the basic time-phased record is designed and updated. So the question arises as to how to handle such subassemblies within an MRP system. MRP users have worked out techniques to deal with this situation. People often wonder whether this type of assembly should be identified in the bill at all. The phantom does not require separate identity in the bill of material, provided there is never

1. An over-run
2. A service part demand
3. A customer return.

Otherwise, it must be separately identified in the bill and item records (stock status) must be maintained. This is so because over-runs, service demand, and returns create a need to stock material, and to control it. But then the MRP user would have to report all transactions for the phantom subassemblies, so that the system can post these and keep the records up to date. This seems like unnecessary effort and paperwork in the case of order releases and order completions.

Fortunately, there is no need to do this. A technique called the "phantom bill" eliminates the need for posting such transactions for these items. (This technique is used; for instance, by the Black & Decker Manufacturing Company, a skilled MRP user.) Using this technique, it is possible to have

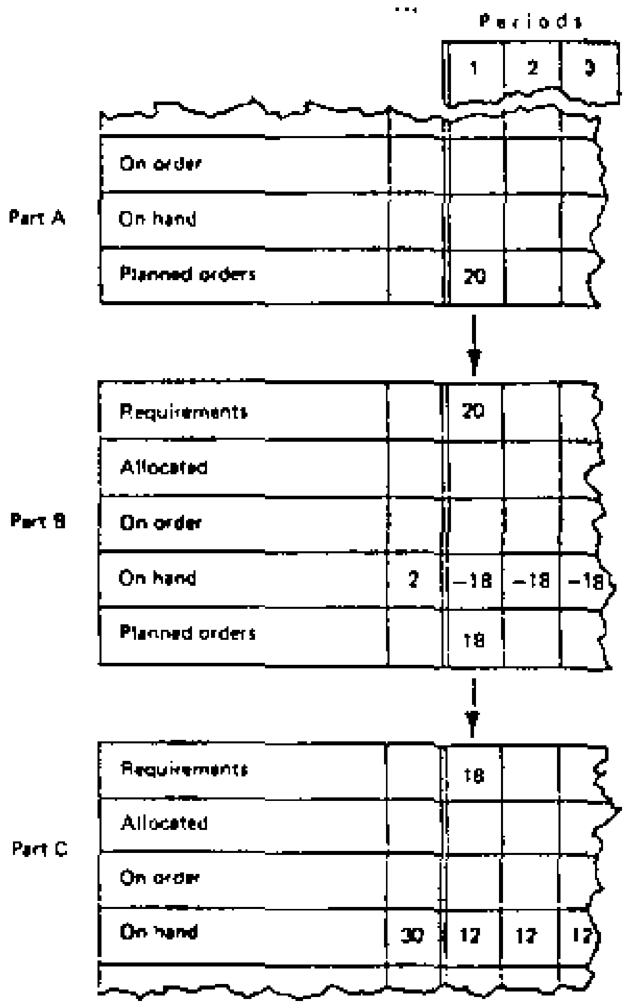

Figure 3.

your cake and eat it. While transactions of the type mentioned do not have to be reported and posted, the MRP system will pick up and use any phantom items that may happen to be on hand. Service part requirements can also be entered into the record and will be correctly handled by the system. But otherwise MRP will, in effect, bypass the phantom item's record and go from its parent item to its components directly.

To describe the application of this technique, let's assume that assembly "A" has a transient subassembly "B" as one of its components, and part "C" is a component of "B." Thus, for purposes of illustration, item "B," the phantom, is envisioned as being sandwiched between "A," its parent, and

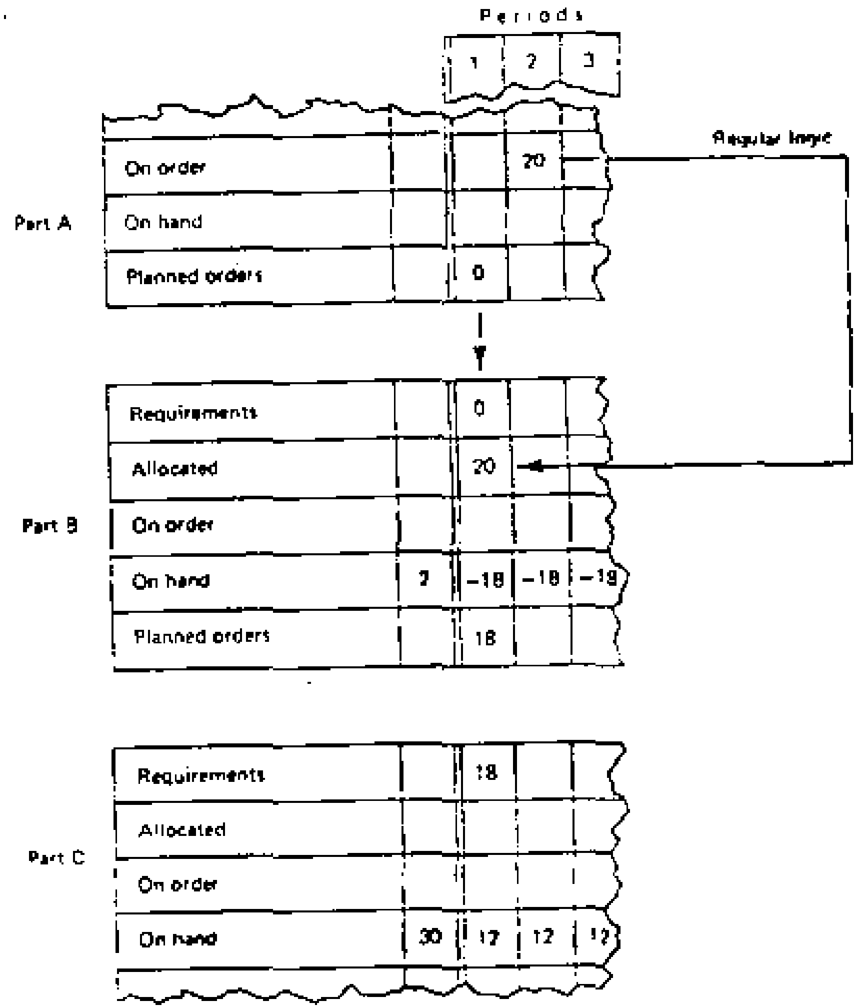

Figure 4.

"C," its component.

To implement this technique, the phantom item is treated as follows:

1. Lead time is specified as zero
2. Lot sizing is discrete (lot for lot)
3. The bill of material (or the item record) is coded, so that the system can recognize that it is a phantom and apply special treatment.

The special treatment referred to above means departing from regular procedure, or record update logic, when processing the phantom record. The difference between the procedures can best be described through examples.

In Figure 3, inventory status data for items "A" (top), "B" (middle), and

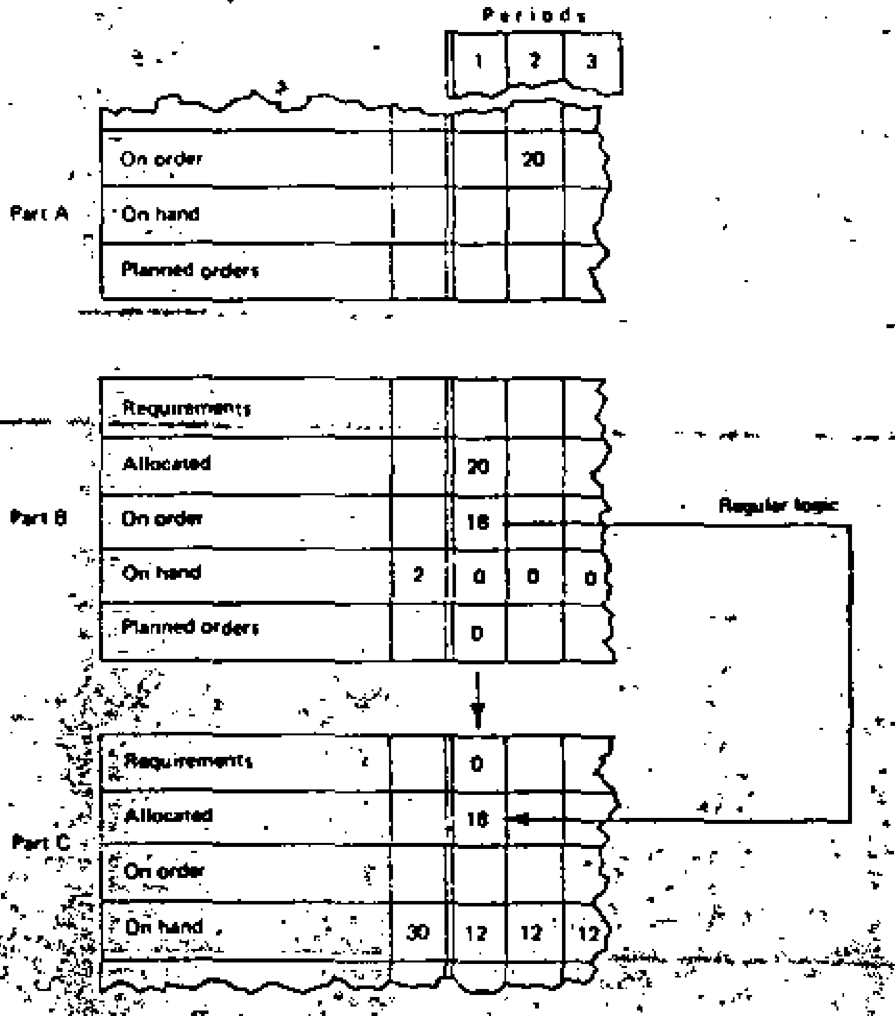

Figure 5.

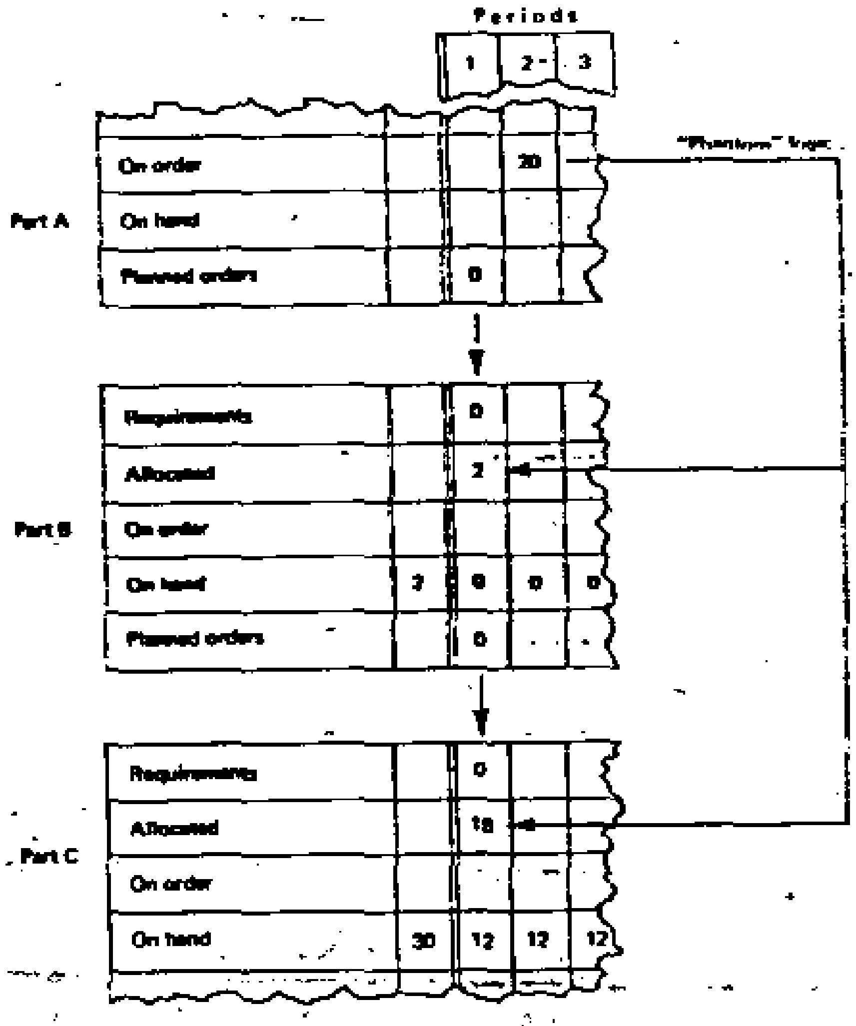

Figure 6.

"C" (bottom) are shown. Note that the zero lead time offset on the item in the middle places the planned order release for 18 pieces in the same period as the net requirement. This, in turn, corresponds to the requirement for 18 "C"'s in the same period.

Following the release of the planned order for "A," the update procedure for item record "B" will vary, depending on whether it is coded as a phantom. In the absence of such a code, regular logic applies. The regularly updated records of "A" and "B" are shown in Figure 4. Record "C" continues unchanged. Following the release of the planned order for "B," item "C" is updated, as shown in Figure 5.

Had item "B" been coded as a phantom, all three records would have be[en] updated in one step, as shown in Figure 6, as a result of the planned ord[er] release of item "A." Note that the release of planned order "A," whi[ch] normally would reduce only the corresponding requirement "B" (as in Figu[re] 4), in this case reduces also the requirement for "C," *as though "C" were direct component of "A."*

Note also that the two pieces of "B" in stock (perhaps a return from previous over-run) are applied to the requirement for "A," and that t[he] allocation has been *distributed* between "B" and "C." Upon closer exami[na]tion of these examples it will be seen that the phantom logic is nothing m[ore] than a different treatment of *allocation*. (Zero lead time and discrete lot sizing are assumed. These can, however, be specified for non-phantom subassemblies also.) Once this step is carried out, regular logic applies, causing the records to be updated and their data aligned, in the correct manner.

The phantom bill technique, as described above, applies to MRP systems of the Net Change type. In conventional regenerative MRP systems the question of posting or not posting transactions to the phantom record is not crucial, because a planned order release does not update component requirements data. Hence, the problem of rebalancing or realigning the planned order and requirements data of the three records does not arise. Following the planned order release of the phantom's parent, the next regeneration will wash out both the requirement and the planned order release for the phantom item.

The objective of not having to post phantom transactions still remains, however, and it can be achieved by, again, setting lead time to zero, specifying discrete lot sizing, and coding the phantom item so that notices for planned order releases are either suppressed or flagged to be disregarded. The MRP system will function correctly.

The problem then becomes one of component requisitioning (for the phantom parent order) and it must be solved by modifying the requisition generating procedure. When some phantom items are on hand, *two* requisitions will have to be generated:

1. One for the quantity of the phantom on hand
2. One for the balance of the order; for the phantom's components.

In the Figure 6 example, these quantities are 2 and 18, respectively.

MODULAR BILLS OF MATERIAL

The term "bill of material structuring" is most commonly used in reference to modularizing the bill of material file. The process of modularizing consists of *breaking down* the bills of high-level items (products, end items) and *reorganizing* them into product modules. There are two, somewhat different, objectives in modularizing the bill:

1. To disentangle combinations of optional product features
2. To segregate common from unique, or peculiar, parts.

The first is required to facilitate forecasting, or, in some cases, to make it possible at all under the MRP approach. The second has as its goal to minimize inventory investment in components common to optional units which must be forecast and thus make it necessary to carry safety stock. We will deal separately with each of these two objectives, and the techniques used to achieve them.

The question probably most frequently asked by people interested in MRP is what do with the bill of material to handle product variations. Under

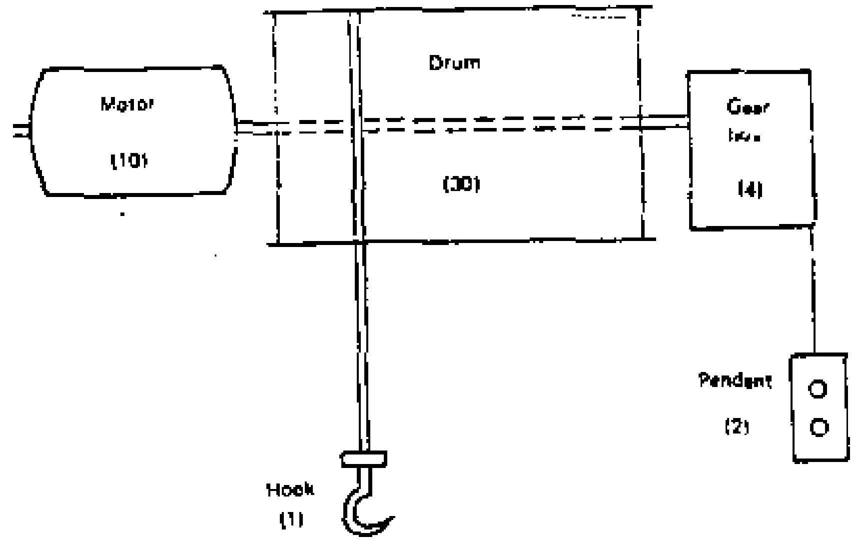

Figure 7.

MRP, these product variations, or optional features, must be forecast at the master schedule level, that is to say, we must be able to forecast end items rather than their individual components, as we do under Order Point. If a product has many optional features, their combinations can be astronomical and forecasting them becomes impossible. Furthermore, if separate bills of material were to be set up for each of the unique end products that it is possible to build, the file would be enormous—too costly to store and maintain. Not only that. A valid master schedule could not even be put together, using such bills, for the MRP system to explode.

The solution to this problem is the modular bill of material. Instead of maintaining bills for individual end products, under this approach the bill of material is restated in terms of the building blocks, or modules, from which the final product is put together. The problem, and its solution, can best be demonstrated on an example. Figure 7 represents a familiar product, a hoist that is used to handle material in a factory.

The hoist manufacturer offers his customers a number of options, in this case 10 motors, 30 drums, 4 gear boxes, and 2 pendants (the hook assembly is standard), from which a customer configurates the specific hoist he wants. Figure 8 shows the schematic product structure of this family of hoists. By assembling the optional features in various combinations, it is possible to build 2,400 models; i.e., 2,400 unique configurations.

Assuming we manufacture this product and wish to implement MRP, the question is what to do with the bill of material. We can see clearly how to write a bill of material for each of the 2,400 models, but we certainly would

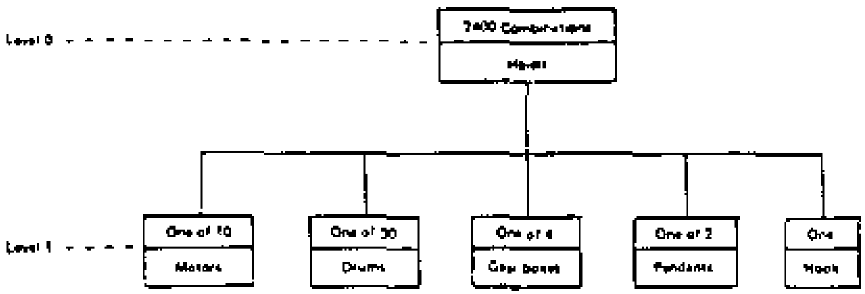

Figure 8.

not want to carry all those bills. Consider this: There is only one variety of hook on this product, but the engineers are probably working on that. If they introduce just one more option—a choice between two hooks, the number of possible configurations will *double* from 2,400 to 4,800—and another 2,400 bills would have to be added to the file.

That is one reason we do not want to set up bills for the end products themselves. But aside from this consideration, with all those bills we would not know how to develop a master schedule showing a quantity of each model needed in specific time periods.

Suppose we produce 100 hoists per month. Which 100 out of 2,400 should we select as a forecast for a particular month? This is clearly an impossible situation. Note that *volume* is part of the problem here. A product family with 100 models is a problem if volume is 20 per month. If volume were 10,000 per month, the forecasting problem would not be nearly as serious.

The solution here *is* to forecast each of the highest-level *components* (i.e., major assembly units) separately, and not to try to forecast the end products at all. That way, we would forecast each of the ten different motor variations, the thirty drum sizes, the four types of gear box, and the two types of pendant.

Specifically, since we only have one hook assembly and want to make 100 hoists during a month, we will need 100 hooks. This quantity would appear in the master schedule, and a bill of material for this "module" would be required to match the schedule. But we have two types of pendant. From previous sales of this product we know that, let us say, 75 percent of the orders call for type "A" and 25 percent for type "B." Applying these percentages to the pendant option, we could schedule seventy-five "As" and twenty-five "Bs." But here we would probably want some safety stock, because the batch of 100 customer orders in any one month is unlikely to break down exactly 75 and 25 percent.

The proper way to handle safety stock under material requirements planning is to plan it at the master schedule level. Thus, instead of scheduling 75 and 25 percent of the pendants we would deliberately overplan and put, let us say, 90 and 30 into the master schedule. (This would not be done in every period; the unused safety stock is rolled forward.) The same approach would be followed for the motor option, the drum option, and the gear box option.

Each of the options, or *modules*, would have to have a bill of material, for use by the MRP system. Under this approach, the total number of bills of material—and the things to forecast—would be as follows:

Motors	10	Pendants	2
Drums	30	Hook	1
Gear Boxes	4	Total	47

This total of 47 compares with 2,400 if each product model had a bill of its own. If the engineers add a second variety of hook, this would only add one more bill to the 47, instead of doubling the file.

At this point, the reader may be wondering how this type of problem is being handled in a real-life situation, if the manufacturer *does not* have the bills set up in modular form. Chances are that there would be several bills, for *some* of the 2,400 configurations, and they would be used for everything by adding and subtracting optional components. Quite a few companies use this "add-and-delete" technique as a solution to the problem we have discussed.

This technique solves some but not all of the problems. Its main disadvantages are vulnerability to human error, slowing down Order Entry, but mainly, failure to establish the proper historical data for option forecasting purposes. Under this approach, the company would most likely use order points and safety stock on the "add-and-delete" components. That would be highly undesirable because it would deprive the user of some important benefits of an MRP system.

But suppose we *have* a certain number of bills for end products, and we want to restructure them in a modular fashion, so we can get away from adding and deleting. How do we go about such restructuring, specifically? We will demonstrate this on the next example. For this purpose, we have to scale down the previous example somewhat, so the solution can be seen clearly. Let us assume that the product has only *two* optional features, the motor and the drum, each with only two choices. The customer can then select between motor #1 and motor #2, and between drum "A" and drum "B."

Figure 9 represents the four bills of material: the first combines motor #1 with drum "A," the second one, motor #1 with drum "B," etc. In the product structure, the end product (model) numbers, 12-4010 etc., are considered to be on level zero. The level-one components, A13, C41, etc., may represent assemblies, but their components are not shown on the chart, so as not to make it too busy.

To restructure these bills into modules, we break them down, analyze and compare the use of level-1 items, and group them by use. For example, we see

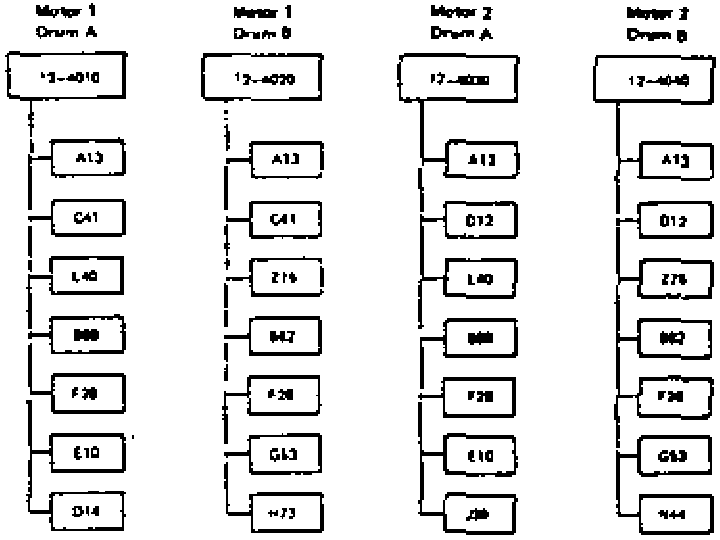

Figure 9.

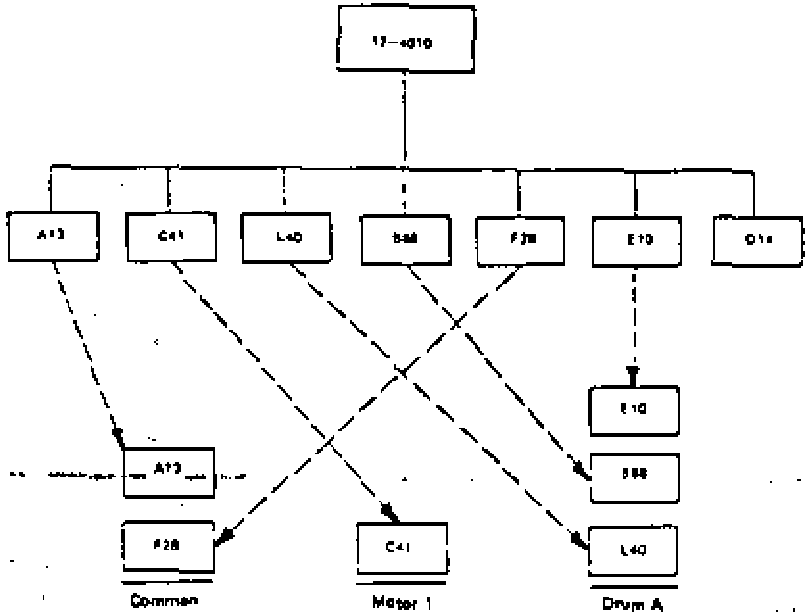

Figure 10.

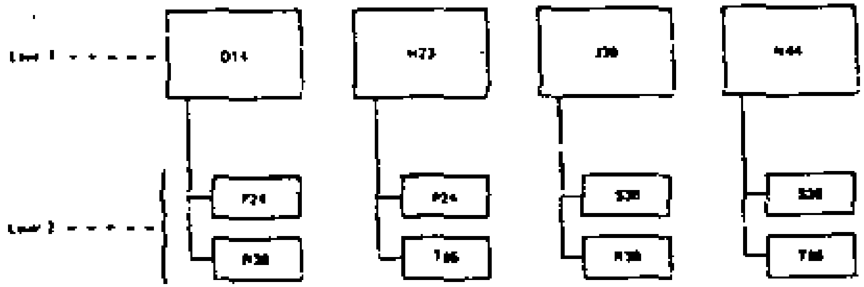

Figure 11.

that the first component in the first bill, A13, is common to all products, and assign it to the *Common* group. The next item, C41, is found in #1-A and #1-B combinations but not in #2-A and #2-B, which indicates that it is *unique to motor option #1*. The item that follows, L40, is *used only with drum option "A."* The remaining component items are similarly examined and assigned to groups. The result is shown in Figure 10.

Note, in Figure 10, that the last level-1 component item, D14, does not fit into any of the groupings. When all of the bills are broken down this way and their level-1 components are grouped by option, items D14, H23, J39, and ℵ44 in our example remain unassigned, because each of them is used only with one or the other of the option *combinations*. Here we must carry the process one step further; i.e., break down these items, as shown in Figure 11, and assign *their* (level-2) components to the groupings by option. The final result is represented by Figure 12, where all of the items involved in our example are grouped into the respective modules.

In our case, we solved the entire problem through the technique of break-down and group assignment. But if items D14, H23, etc. had not been sub-assemblies but piece parts, we would not have been able to break them down. In a case like that, the part that is used only with a certain combination of options should, if possible, be redesigned, particularly if it is an expensive item.

Low-cost items of this type need not be re-engineered, because we can

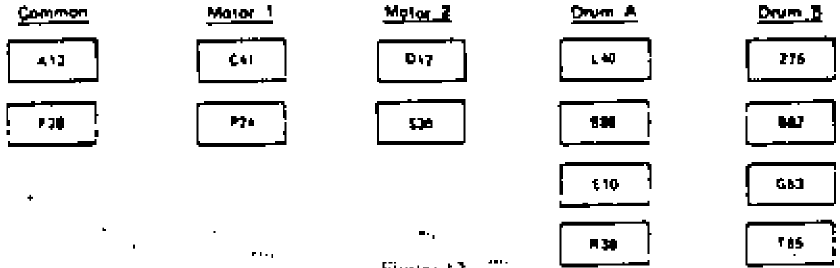

Figure 12.

afford to overplan them and carry some excess inventory. In the modularizing process, such parts can simply be assigned to more than one grouping. For example, item D14 (Figure 9) could be duplicated in both #1 and "A" modules (Figure 12), ensuring that it would never be planned short. Another solution, of course, is to forecast (and over-forecast) the option combinations for purposes of ordering this type of component.

Let us recap what we have done with the example under discussion, up to this point. We have *abolished* the end product numbers and we have done away with their bills of material as unnecessary for purposes of MRP. Where the final product formerly served as the end item in the bill of material, we have now *promoted* level-1 items (and in one case, level-2 items) to end item status.

This procedure established a new, modular *planning bill*, suitable for forecasting, master scheduling, and material requirements planning. The job of restructuring is not finished, however. The former level-1 items, D14, H23, etc., that are excluded from the planning bill cannot simply be abolished. These items will eventually have to be assembled, and the production control system has to be able to place orders for these items, schedule them, and requisition their components. These bills must therefore be retained for the purposes just mentioned.

This represents another technique of bill of material structuring: the establishment of *manufacturing bills*, or *M-bills*, which together constitute the M-bill file. These bills are coded to distinguish them from planning bills, so that the MRP system will, in effect, bypass them. M-bills are not involved in the process of component requirements planning. They are used for purposes of assembly only. M-items are built against the final assembly schedule, usually to customer order (or warehouse order), using the components planned through MRP.

The principle involved here is that in modularizing the bill of material at whatever level, *end product bills (level-0) can be abolished entirely but not any bills formerly on level-1 or lower.* These must be segregated in the M-bill file and retained for purposes of ordering, scheduling, costing, etc. Specifying options in Order Entry (or in scheduling a warehouse order) will call out and reconstruct the proper bills for individual end products, but not for lower level assemblies that have been removed from the planning bill file.

In the example we have been using, the total bill of material file would consist of:

1. *The planning bill file*
   comprising bills shown in Figure 12.
2. *The M-bill file*
   comprising bills for D14, H23, J39, and N44.

The Production and Inventory Control Handbook* contains an example of bill of material restructuring that illustrates another technique. Namely, *reassigning* components from one bill to another. It is in chapter 17, and the reader is referred to the detailed discussion and illustrations contained there. The example used involves an engine, transmission, intake manifold, carburetor, and flywheel housing. This technique is really another version of modularizing. The difference is that the items being broken out, like the manifold, are *not* being promoted to level-1 status but are reassigned as components of another level-1 item, such as the carburetor.

This will get the right components planned but, because the manifold, for instance, does not *really* get assembled with the carburetor, certain new problems will be created. For example, stock requisitions or service parts orders for the carburetor should not call out manifolds, the cost build-up of the carburetor must not include the manifold, etc. Special procedures would have to be established within the system to handle this. Two bills would have to be maintaaned for the carburetor. One, a planning bill, with the manifold and another one, an M-bill, without it. But in this case, it would not otherwise be necessary to set up two carburetor bills if the illegitimate components were not assigned to it.

This technique of reassigning components is unnecessarily complicated and vulnerable. The straight modularization technique demonstrated on the previous example is cleaner and gets the job done in a simpler fashion. We mentioned earlier that one reason for modularizing is to disentangle option combinations, for purposes of forecasting and master scheduling. In our example of the hoist, this has been accomplished by establishing the modular planning bill shown in Figure 12. The other objective of modularization, segregating common from unique (optional) parts for purposes of inventory minimization, has not been fully met, however.

In modularizing the bills, we assigned level-1 items to groups, by option. But those items were *assemblies*, and they may contain common components. For example, a subassembly that is only used for motor #1 could have some common parts with another subassembly used for motor #2. Requirements for such common parts will be overstated, if they are included in the safety stock for *both* options. If we want to get at these common parts, we would have to tear the bills apart even further. In some cases it is desirable to do that, but if this technique is carried to its extreme, we might finally end up with a planning bill that has only piece parts in it and no subassemblies. The ultimate module of the product is really the piece part.

The question is this: When we do modularize, how far down the product structure should we go? What we are really doing when we modularize is determining the right level in the bill of material at which to forecast. Whether we should forecast the subassembly itself or just its components—and that is the question here—depends on *when* we need to assemble it.

*Production & Inventory Control Handbook, McGraw-Hill, 1970.

We have two choices. Either we assemble it as a function of executing the master schedule, through MRP. This means assembling to stock, or *pre-assembling*, before the end product itself is scheduled to be built, which is probably after receipt of a customer order. Or we defer putting this subassembly together until such time when we build the end product. The making of the subassembly then becomes a function of executing the final assembly schedule. The decision between these two alternatives is pretty much dictated by the nature of the product in question, and by the nature of the business. Lead times and the economics of subassembly operations will determine, in each case, whether the item should be pre-assembled or whether it can wait until final product assembly.

Let us take the pendant on the hoist as an example. We can wait and assemble the pendant, and *its* subassemblies, when we built the final hoist to customer or warehouse order. But, on the other hand, we may want to have the pendants in stock when the order comes in, so as not to have to assemble them one at a time. If this is the case, we would have to leave the respective bills alone, even though some common parts will consequently be tied up in the pendant assemblies. The master schedule would then contain pendant bill numbers rather than their component numbers.

In trying to arrive at the answer to the question we are examining here it is helpful to distinguish between the

1. Master production schedule
2. Final assembly schedule

The master schedule represents a *procurement and fabrication schedule*. The final assembly schedule, created later in time, must stay within the constraints of component availability provided by the master schedule through the MRP system. (These schedules may coincide where the product either contains no options, or is small and simple, etc.) Different subassemblies are under the control of these two schedules, and in modularizing bills of material we are, in effect, assigning a given subassembly to either one of these schedules:

1. To the master schedule, by retaining it in the planning bill
2. To the final assembly schedule, by breaking down its bill (i.e., transforming it into an M-bill)

Thus the question of how far down the product structure one should go in modularizing tends to answer itself when the bill for a particular product is analyzed, and when we look at the nature of the various subassemblies in a particular business environment.

To conclude the discussion of modular bills of material, it may be proper to reflect on the objectives of modularization. Besides the specific objectives brought out earlier, there is a broader, more fundamental reason. And that is to maintain flexibility of production with a minimum investment in materials inventory. We want to offer a wide choice of products and to give maximum service to customers, and at the same time keep component inventories down. Modular bills of material are intended to help us do just that.

PSEUDO-BILLS OF MATERIAL

There is one more problem that is related to the modular bill of material. When the bill is broken down in the process of modularizing, various assemblies are promoted and become end items; i.e., highest-level items with no parent. This tends to create a large number of end items. Because it is the end items that will have to be forecast, and because the master schedule has to be stated in terms of these end items, we could end up with hundreds (or thousands) of end items, too many to work with.

Fortunately, there is a simple solution to this. We certainly want the smallest possible number of things to forecast, and the smallest possible number of end items shown on the master schedule. To accomplish this, we can use the technique of creating "pseudo-bills of material." If we go back to Figure 12, where the newly created end items are grouped by option, there is nothing to stop us from taking any group of such items and creating a pseudo-bill to cover all of them. We have done so in Figure 13, where an artificial parent has been assigned to each group, and a new series of (pseudo) bills has been created.

These new bills, sometimes called ***super-bills*** or ***S-bills***, are an example of ***non-engineering part numbers*** being introduced into a restructured bill of material. An S-number, such as S-101 in Figure 13, identifies an artificial bil of material for an imaginary item that, in reality, will never be built. The onl purpose of the S-number is to facilitate planning. With the S-bills set up when we forecast drum size, for instance, we forecast S-104 and S-105 only These pseudo-bill numbers will also represent these options in the maste schedule. The MRP system will explode the requirements automatically fron

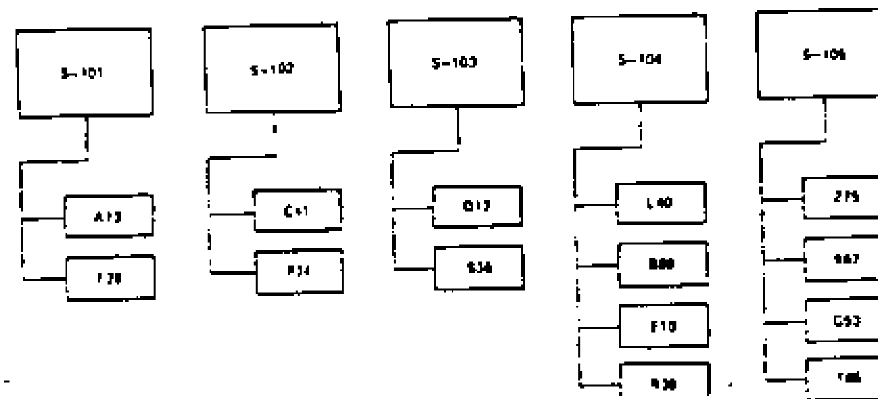

Figure 13.

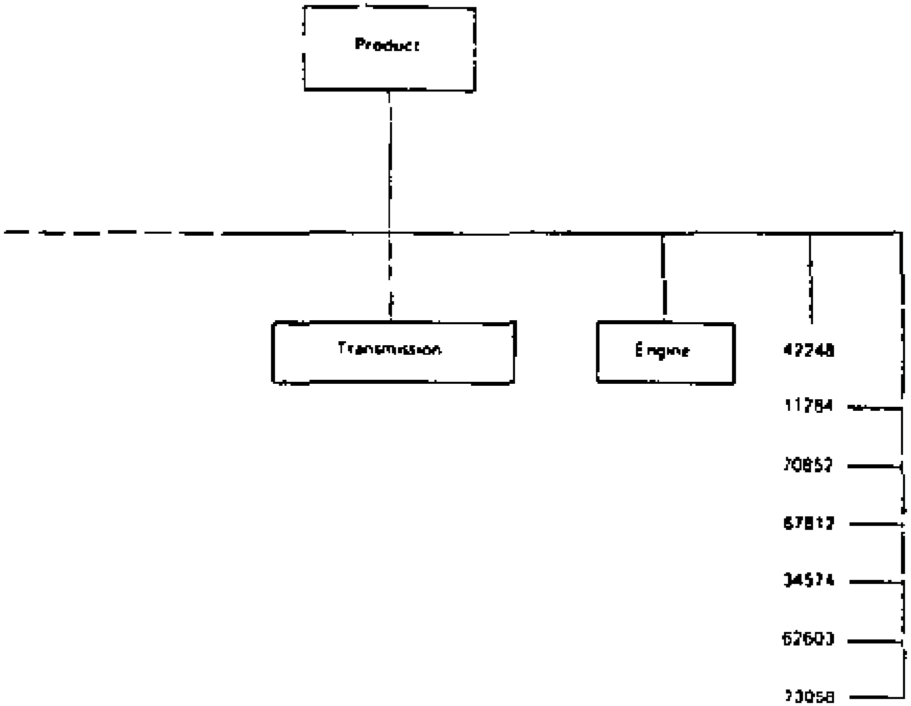

Figure 14.

this point on, using the S-bills in the bill of material file.

A total of 47 S-bills (one for each option plus one for common items including the hook) would cover the original (non-simplified) example of the hoist represented in Figures 7 and 8. The 47 compares with 2,400 end product bills, or with several hundred end item (level-1) bills.

In this article, the terms "S-bills," "S-number," and others, are being used for lack of standard terms. The terminology in this whole area is unfortunately entirely non-standard, as the subject has been almost totally neglected in literature. One of very few exceptions is the article by Dave Garwood* in which he described the results of restructuring the bills of material at Fisher Controls Co. In his article, the term "partial parts list" (PPL) corresponds to the S-bill, and the term "Item" to an option or option grouping.

Another pseudo-bill term in current use is the "Kit number" or "K-number." This technique is used by some companies that have a lot of small loose parts on level one in the product structure, as in the example in Figure 14. These are often the fasteners, nuts, and bolts, used to assemble the major assemblies together. If you do not want to deal with all these parts individually—and you certainly do not under an MRP system—you can put them into an imaginary bag, as depicted in Figure 15. You can then assign a part number to this bag of parts and treat it, in effect, as an assembly. This means setting up a bill of material for such a kit number (also shown in Figure 15).

*"Stop: Before You Use the Bill Processor," by D. Garwood, *Production & Inventory Management*, Second Quarter 1970.

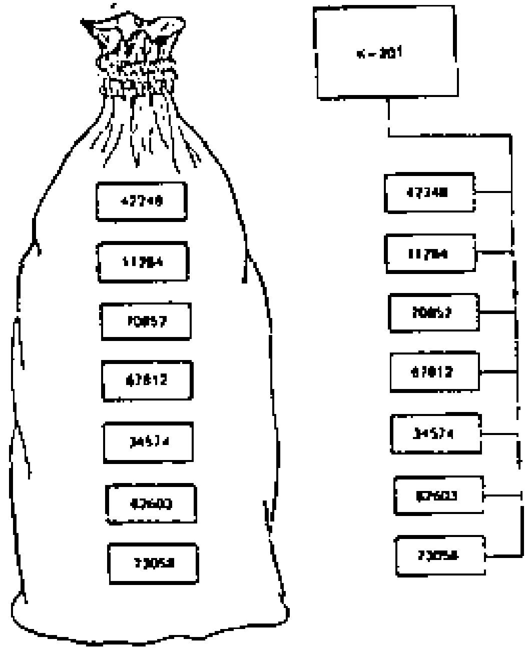

Figure 15.

The principle is the same as in the case of the S-bill—assigning a single new identity code to individually coded items that constitute a logical grouping, and employing the format of a bill of material to relate the items together for system purposes. The K-bill is another non-engineering part number created in the process of structuring the bill of material. These artificial identity codes have little to do with the design of the product and are not part of the product specs, but are created for more convenient planning, forecasting, and master scheduling.

These newly created bills, along with the M-bills we discussed earlier are sometimes collectively called the *superstructure*. The superstructure, once established, must then be maintained along with the rest of the bill of material file. This is a new job, which means that the cost of file maintenance will normally go up.

CONCLUSION

In the previous sections of this article we have reviewed modularization, which does away with end product bills and creates separate planning bills and manufacturing bills. We have seen how artificial bills are created in the process of restructuring, and for what purpose. We have also touched on the relationship of item identities to material requirements planning, and on the treatment of "phantom" assemblies. All of this goes to show that by making these kinds of changes, we can put the bill to new uses.

There are still other uses that can be assigned to the bill of material. An interesting example of modifying and using the bill of material in a new way is to expand the traditional concept of the bill to include other materials which may not actually be part of the product, but which are consumed in its making. For example, a ball bearing manufacturer has added special grinding wheels to bills of material for ball bearings. In effect, they are saying that a "part" made of a portion of the grinding wheel goes into each bearing assembly. The "quantity per" is the fraction of wheel life to make one bearing. Adding this item to bills of material makes it possible for this company to project requirements for expensive grinding wheels and thus minimize investment in this inventory, as well as to reduce the possibility of a shortage of grinding wheels.

An electrical machinery manufacturer has added electrical specification numbers for power transformers to bills of material. The assembly orders generated from these bills then show not only the parts that go into the assembly but also the proper specifications for final inspection and test.

In conclusion, we want to indicate who does and who does not need to restructure the bill of material, as a pre-condition to successful MRP system operation. Where the product line consists of a finite, limited number of items (models), modularizing the bill, or any other changes for the sake of bill of material structure may be unnecessary. For example, a company making power tools—a highly successful user of MRP—did not have to restructure bills of material. In their business the bill simply is no problem, because they manufacture only so many varieties of power drill, power saw, etc., in large quantities. Furthermore, the product is relatively simple and small, in terms of the number of different components used per unit of end product. With a product line like that, it is feasible to maintain complete bills for each product model, and forecast and plan by model.

On the other hand, bill of material restructuring is called for where the product line consists of a virtually infinite number of end products, due to complexity of design and wide choice of optional features. Modular bills of material make material requirements planning possible for such diverse products as highway truck trailers, mining machinery, gasoline station pumps, etc elevators, office machinery, farm machinery, computers, machine tools, instruments, industrial tractors, and a multitude of others, who have the common problem of an almost endless product variety that makes it otherwise impossible to develop valid master schedules.

The study of how bills of material should be constructed is therefore a vital part of the work of designing and implementing an MRP system. Structuring the bill of material requires some real cooperation from the engineering department, and sometimes this can be a problem. After the bill is restructured, it can no longer "belong" to the engineers exclusively, and that can sometimes be a problem also.

The bill of material can and should be more than just part of product specs. It should also be viewed and used as a *tool for planning*. The resistance by some engineering departments to change in bill of material format, structure, maintenance, etc., cannot really be justified. After all, the engineers create the bill so that, by definition, somebody other than the designer can make the product. The bill of material is, therefore, really made for others, in the first place. And it would seem to follow that it should be structured for the *user's*, not the designer's, convenience.

An ex-engineer friend of ours put it this way: "When I worked as an engineer, I saw the creation of the bill of material as the *last step in the process of design*. But when I later moved into production and inventory control, I began to see it as a *first step in the process of planning*."

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ADVANCED REQUIREMENTS PLANNING SYSTEM CUTS INVENTORY COSTS, IMPROVES WORK FLOW

EARLE QUIMBY
Markem Corporation, Keene, N. H.

"The right part in the assembly room at the right time."

Though simply stated, this goal always has presented a challenge for manufacturing management. It is difficult enough to maintain an economical flow of parts when the company is small and sales stable; but when the product line becomes complex and sales improve at a healthy rate, the pressure on the manufacturing plant grows dramatically. Then the right part *must be* in the right place when it's needed.

We believe we've "turned the corner" on this problem at Markem Corporation. An advanced requirements planning system, using a medium-size computer, is helping pull together all the threads which make up manufacturing planning and production. By combining separate but interrelated systems for inventory and production scheduling, this new capability already has reduced inventory substantially even as sales have increased by better than 15 percent.

Most important, the profit percentage has been holding up and we've experienced a record shipping period. We're pleased with our present ability to get parts through to the assembly floor to meet our schedules.

We are a growing company, serving many industries with marking equipment that is highly customized. In fact, about 75 percent of our products require special engineering features to meet customer requirements. Markem was founded in 1911 by F. A. Putnam, and is still a privately owned company. The first products devised by Mr. Putnam were an ink and a marking machine which printed size information on shoe linings.

Today, we make marking machines and special inks and printing type for practically any product. Our Marketing Division and field sales force are specialized by industry and are supported by similarly specialized research and development activities. One of our newest products, a drug capsule printer, can mark 400,000 capsules per hour. Another specialized machine automatically feeds and prints on transistors and other miniature electronic components. Markem has become the leader in industrial identification equipment.

The Mechanical Products Division has the responsibility for producing a wide range of machines and printing types; the Chemical products Division, also located in Keene, produces inks and printing foils. Sales offices are located throughout the United States and Canada, and in certain European countries; sales agents are located around the world. In 1967, the Milford-Astor Group, in Manchester, England – a manufacturer of hot stamping equipment and foils – was acquired.

Company sales have been growing at a steady rate of 10 to 15 percent in recent years; annual sales are in the $15-to $18-million range.

To fill machine orders, the Mechanical Products Division manufactures about 80 different models which in turn lead to about 150 combinations. Three batch assembly lines are in operation, where basic parts are assembled to build basic configurations from which the final machines are produced. It is here that the critical need for "the right part at the right time" is felt. If this line does not keep moving smoothly, shipment dates cannot be met.

We began thinking of applying modern information processing methods to manufacturing planning and control in the mid-1960s. Our experience with automatic data processing dates back to 1950, when we began to use punched-card equipment for accounting and sales analysis applications. This was updated in 1966 with a System/360 Model 20.

With the decision to extend data processing to manufacturing operations, we ordered a Model 30 and set out to achieve an effective inventory control system which we envisaged as the first step towards a comprehensive plant system. We used the IBM Bill of Material Processor – a programming system which organizes production information on magnetic disk files – to create a product structure file. In December, 1968, IBM released another set of programs, Requirements Planning, and ours was one of the first companies to put it to use. Requirements Planning uses sales forecasts and customer orders to determine component part and sub-assembly requirements by time period, generate action notices or orders for items requiring production or purchase, and plans replenishment orders. Both the Bill of Material Processor and Requirements Planning are part of an interrelated Production Information and Control System (PICS).

Our Model 30 includes three 2311 magnetic disk units which use interchangeable disk packs – or electronic files – a punched card input/output unit, and a high-speed printer. Production information, organized as a data base and maintained on other disk packs, is broken down into separate files. The primary files include:

1. An item master file. Maintained on one disk pack, and covering all of the 15,000 items we inventory – raw materials, parts, and assemblies.
2. The product structure file, organized under the Bill of Material Processor Each product is structured in four levels – raw material, part, subassembly and machine. Each level references both the prior and next higher level permitting both explosion and implosion of requirements.
3. The subordinate master item file. This includes data on the 6000 item thus far selected to be controlled under Requirements Planning.

Two criteria determine if a part is included in Requirements Planning: usage and dollar value. For the past two years, we have been ABC-listing inventory with the most expensive items at the top. Thus, all A and B, and most of the items, have been included in requirement planning.

The usage criterion we established is *how* the part is used. If 90 percent of usage is in fabrication of new machines, as opposed to sale as a repair part, it is included in Requirements Planning.

During the weekly run of the Requirements Planning System, the three disk files are on-line, or directly linked, to the computer. They hold operating system/requirements planning instructions, item master file and product structure/subordinate item master file. Thus, all the data needed to explode and project requirements across different manufacturing periods are immediately available.

The cycle actually begins with our yearly sales forecast. This is integrated with orders in-house at the time the forecast is made and a year-long assembly schedule, projected in five-day working periods. As orders come in, they are used to fine-tune the forecast. This fine-tuning extends over a three-month period; orders still in the engineering department when this forecast is made are picked up later at the subassembly level.

Based on the data developed in the three-month forecast, the batch assembly lines are scheduled one month ahead. Basically, the information at this stage tells us how many and what machines we will be manufacturing. Scheduling data which includes machine numbers, quantities needed and dates to be shipped, is sent once a week to the data processing department, where it is punched on cards. The cards are fed into the computer with the previously-described on-line data base. Automatically, the system explodes requirements for each machine to be produced, at each level of the product structure.

If the system finds an item with enough quantity on hand, it goes no further; if not, processing continues through each product level, testing the inventory balance at every level. When the gross requirement for an item or part is not covered by on hand or on order balance, a net requirement is generated and a planned order developed.

The result is a comprehensive requirements generation report which prints the critical details of each item extended across the five-day calendar periods, one year ahead. Shown are: the gross requirements for the item in each calendar period; existing open orders and those projected for specific periods; the anticipated inventory balance for each period as well as the current balance; net requirements per period; and offset requirements. Also shown is the quantity to be ordered if net requirements in any period fall below the minimum for an item.

Prepared at the same time is an exception report highlighting conditions that might otherwise be missed. For example: for a given item the report will show that although a planned open order exists, gross requirements are covered by inventory on hand. Another exception might show that an order is needed sooner than the time period anticipated. The programming system allows for 19 such exceptions to be reported.

Both the requirements generation and exception reports – which are developed in four hours' running time on the computer – are sent to the manufacturing planning and control department. The items to be ordered are noted; the exceptions noted; projected requirements for each item studied through each time period; and actual orders initiated accordingly. These are fed back to the data processing department, where job packets are printed and order information accumulated. Each week, prior to the requirements planning run, the orders initiated during the past week are fed into the system for posting to the subordinate item master file. This automatically clears any previous order data and substitutes the new information. Orders in the open order file are closed out as information from the plant floor flows back to data processing.

This, in brief, is the system as it is operating now. We have made certain changes and additions to the programming systems supplied by IBM. These include the forecast percentage, a projected balance line printed on the requirements generation plan, and the extension of anticipated parts usage for repair purposes throughout the year.

The next step in our manufacturing system plan will be implementing the Capacity Planning Program. This phase will handle long-range planning: taking the load of jobs to be run in the plant, measuring them against available manpower and machines within required time periods, and developing start dates in order to establish a leveled load pattern while meeting customer shipment requirements.

We also plan to install a television-like display station in the manufacturing planning and control department to serve as a direct link to the computer system. This will permit instant retrieval of inventory and other data, quick updating of information, and other functions, such as checking individual open orders. Another computer terminal in the engineering department will be used to process engineering changes, and to retrieve bill of material data. We hope to use one of these terminals for order entry.

The basic goal in manufacturing is to ship finished products on the closest possible schedule, keeping customer service at a high plane, while holding inventory and manufacturing costs to the minimum. We are convinced this can no longer be done without the computer, and have proved that while the transition to modern information processing is a long-range effort, the payoff is very real.

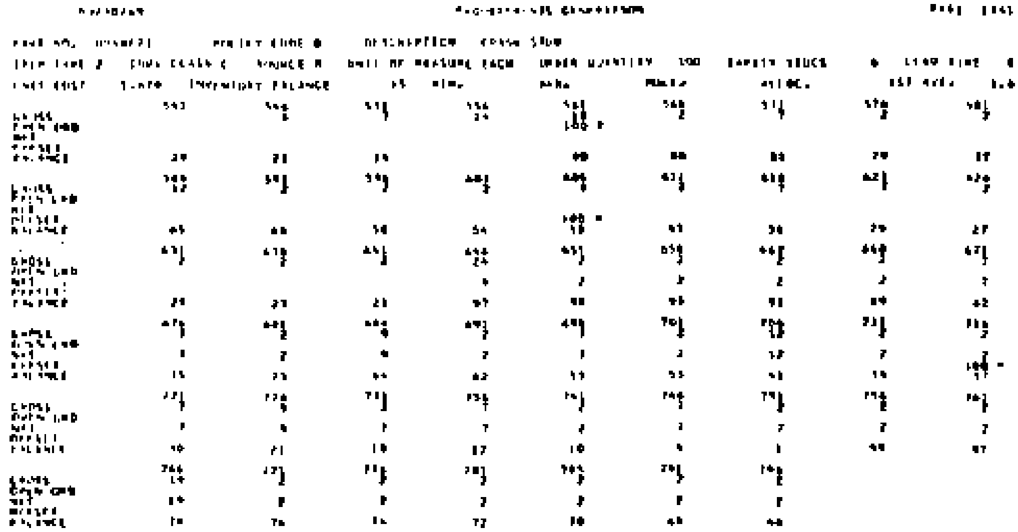

Exhibit A. – A sample printout of the requirements generation plan produced on the IBM System/360 Model 30. This printout covers one part – a crank stud – and extends requirements over 52 five-day working periods. At the top is printed descriptive and identifying information. On the second line, "Source M" indicates the part is produced in house; the word "each" next to unit of measure indicates the measure is in discrete numbers rather than pounds; the order quantity indicates that an order for 100 units will have to be placed to meet requirements in one of the time periods; the lead time shows that eight working periods are needed. In the third line is shown the current inventory balance (min/max/multiple order quantities and allocated stock are not printed on this report); the final item on the third line indicates the item's percentage use as a repair part. Along the left are headings for each of the time periods shown – gross requirements each period, open orders, net, offset requirements, and balance. The figures starting with 541 are the five-day working periods. Assuming that 541 actually referred to the week of September 24, the report shows that on October 22 – calendar figure 561 – an open order for that part is due to be completed and 100 units will be added to stock. This existing open order is indicated by the L sign.

Extending gross requirements into the future, the report shows that in period 606 another order should be placed; the asterisk indicates it is an anticipated order. This report is produced weekly for each of the 6,000 items or parts controlled under the requirements planning system.

RUN DATE – 09/16/69 REQUIREMENTS PLANNING EXCEPTION REPORT

ITEM NUMBER	EXCEPTION CODE	REQUIREMENT DATE	REQUIREMENT QUANTITY
0110358	19	555	250
0110693	19	550	150
0120006	19	555	20
0120013	19	590	250
0120225	19	563	200
0120362	19	550	60
0130427	19	705	50
0130482	19	560	50
0130529	19	545	50
0130546	19	605	150
0150009	19	535	30
0150106	19	625	70
0160255	19	655	200
0170209	19	555	150
0170643	19	535	100
0190498	19	560	50
0200153	19	660	100
0200734	19	565	250
0200381	19	540	25
0200362	19	560	75
0200383	19	610	25
0200456	19	550	90
0200457	19	545	60
0220092	19	650	35
0220122	19	575	40
0220231	19	590	60
0220232	19	590	100
0260009	19	540	25
0260009	19	550	25
0260025	19	560	70
0260064	19	593	25
0260073	19	575	10
0260225	19	560	75
0260229	19	565	75
0260461	19	545	40
0260461	19	595	40
0260468	19	545	50
0260471	19	555	10
0260472	19	555	40

Exhibit B. – After the requirements generation plan is printed, the IBM System/36 Model 30 also produces an exception report to highlight conditions which might otherwi be overlooked. In the sample shown here, the exception code (19) indicates that for th items or parts listed on the left, an open order is due to be completed in the five-da calendar period shown under requirement date – but net requirements for this part exist i an earlier period; in other words, the part will be needed sooner than indicated on th requirements generation report. This permits Markem manufacturing planning and contro management to take whatever action is necessary to assure the needed parts will be on han in the time period indicated. The IBM requirements planning system incorporates 1 exception situations. The system identifies them automatically and prints them out a shown.

About the Author—

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MATERIAL REQUIREMENTS PLANNING— THE KEY TO CRITICAL RATIO EFFECTIVENESS

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Critical Ratio is a simple yet sound method of expressing the relative priority of work in process, by relating the *time remaining* before an item is due, to the amount of *work remaining*. For example, if a part in process is required in five days and it has ten days of work remaining, it has five days over ten days or a ratio of $.5(\frac{5}{10} = .5)$. This is an expedite priority, since the job will have to be done in half its normal remaining lead time if it is to be completed on schedule. Ratios of 1.0 mean the job is exactly on schedule, ratios greater than 1.0 mean the job is ahead of schedule, and anything less than one means behind schedule. This technique for shop scheduling and job sequencing can be a powerful tool *provided* the source of the time and work remaining is accurate and reliable.

Of the two elements of the ratio, *time remaining* (to order due date) is self-evident, and *work remaining* is easy to express since it (the lead time remaining) can be determined by the summation of the transit time, queue time, set-up and run time for all the operations on the routing still to be performed. Care must be taken to insure that the queue times are correct and reflect the desired level of float. As the work is performed and reported through some form of data collection procedure, the *work remaining* decreases, which in turn alters the calculation of the ratio.

This is a simple mechanical procedure which relies primarily on timely shop reporting and accurate routings. The difficulty with critical ratio occurs with the *time remaining* element of the ratio, although, at first glance, its value seems self-evident. The lack of success critical ratio has experienced in the past years can be attributed to the inaccuracy of the *time remaining*. The real problem is with the *integrity* of the due date.

A critical ratio shop floor control system will deteriorate quickly when the foreman discovers he is working to priorities that do not coincide with the *real* needs of the assembly department. Thus the effectiveness of shop execution is directly contingent on the integrity of the due date the inventory system generates. What is the order due date, and does it coincide with the date of real need? The inventory system must answer this question every time critical ratio priorities are calculated.

Materials Requirements Planning can answer this question because it has the inherent capability to plan and maintain order due dates valid. Generally, Material Requirements Planning is thought of as a supercharged computer technique for ordering material and for inventory planning, which it is. But it also has the critical role of keeping shop priorities up-to-date. It is not unusual for a company that has severe shop scheduling problems to be attracted to Material Requirements Planning for its shop floor control capability and not solely for purposes of inventory planning and ordering. Because it has this ability to maintain due dates valid, it is ideally suited to drive a critical ratio shop floor control system.

Materials Requirements Planning can react dynamically to changing material needs. As the master schedule is changed because of reschedules, expedites or cancellations, and as this is processed by Material Requirements Planning, the *time remaining* is altered by the revised shop order due dates, and the new ratio will reflect these changes to the shop floor. This can be done as often as it is necessary to update the inventory files and communicate schedule information to the foremen. This flexibility is a characteristic that is simply not available with reorder point techniques.

A material control system based on reorder points considers only the usage characteristics of the part itself, and virtually ignores the relationship to its position in the bill of material, and the timing of its parent end item on the master schedule. Consequently, schedule changes to highest level assemblies will not be reflected down through the bill of material to all its lower level components. This insensitivity to schedule change can be costly, especially when it becomes necessary to retard an end item assembly and its components.

Changes can be the result of customer requests, forecast adjustments or the need to be realistic and reschedule an assembly to coincide with the late receipt of one or more of its components. With Material Requirements Planning, the resulting change of the due date on all orders affected can be communicated to the shop floor before valuable capacity is consumed, and before more labor dollars are put into inventory. The critical ratio will adjust to a slack priority which tells the foreman to shift his attention to other jobs with higher priorities.

The utility of Materials Requirements Planning is further demonstrated by its ability to raise the red flag on material in process that has no requirement. Engineering changes, quantity changes or customer cancellations can suddenly eliminate the need for parts. It is obviously important to stop these orders in process before the costs of surplus or obsolescence increase. When there are no requirements, the *time remaining* equals infinity. The critical ratio will reflect this condition and signal the foreman to stop all further work and remove the job from the floor.

A common problem with critical ratio is maintaining a meaningful priority on work that is past due. When the *time remaining* is zero (the due date is today) and there is still work to be done, the value of the critical ratio is zero. If *time remaining* continues to be expressed as zero when the order is one or more days past due, the zero value becomes meaningless. Which of the zero jobs should the foreman work on next?

This can be a problem when the dispatch list reflects a number of such jobs. Typically, this situation is overcome by expediting, rush stickers, or perhaps a sophisticated algorithm which converts the zero to some kind of past due priority index that the foreman does not understand. With Material Requirements Planning, it is possible to resolve this problem. A time phased past due permits the time remaining to be expressed as a negative number, which produces an understandable *minus* priority value that is still relative to all other jobs on the dispatch list.

There are other options available through Material Requirements Planning that can be applied to critial ratio shop floor control. Some of these techniques are: audits to insure the calculated lead time or *work remaining* is consistent with the offset lead time used in the inventory part master record, or utilizing pegging methods that discriminate between work-in-process for customer orders and orders being run against an inventory forecast. Knowing which jobs are for customers and which are for inventory can aid shop planning and maintain proper emphasis.

The important fact is that critical ratio with Material Requirements Planning presents a viable means of executing the master schedule. The results of this combination further demonstrate the power and versatility of Material Requirements Planning, and indicate why it must be the keystone of a computerized production and inventory control system. Again, its capacity to plan and maintain due dates valid enables production control to give the foreman what he wants—a schedule that is truly current.

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TO ORDER POINT OR NOT TO ORDER POINT

Oliver W. Wight

Plossl and Wight Associates, Wilton, Connecticut

THE ORDER POINT – A GREAT CONCEPT

The order point is a fundamental concept in inventory management and many companies use it on all items in inventory. Experience in practice has shown that order points are not always the best re-ordering technique and, in fact, that most items in the inventory carried by the typical company that fabricates and purchases *components* (this term includes subassemblies, parts, and raw materials) to be assembled, can be reordered far more effectively using other approaches.

Before discussing the problems involved with order points and the techniques that should be used instead, some background information on order points should be reviewed. Basically, an order point establishes the level at which a replenishment order will be placed. The order point construction is:

$$OP = D_{LT} + R$$

where the order point is equal to a forecast of demand during lead time plus reserve stock. If, for example, lead time were six weeks, demand were estimated to be approximately 100 units per week and a safety stock or reserve stock equivalent to a two week supply were planned, the order point would be equal to 800 units and when inventory reached this level, a calculated order quantity (often determined using an *Economic Order Quantity* formula) would be reordered.

There are many variations on the basic order point theme. The well known "two bin" system establishes a quantity in one bin as the order point and when the other bin is depleted, a reorder is placed. The "min-max" system establishes a *minimum* (order point) and when inventory reaches this level, a quantity is reordered to bring the inventory up to a *maximum* (order point plus order quantity). These order point systems are called *fixed order quantity* systems as distinguished from their near relatives, the *fixed interval* or *periodic* review systems. In a fixed order system, variations in demand cause variations in the *timing* of re-orders; in a fixed interval system, it is assumed that inventory will only be replenished periodically and thus the *quantity* ordered at each review period varies as demand varies. In the discussion that follows, all of these techr[illegible]es are categorized as "order point type systems".

Intuitive approaches to calculating order points usually involve some across the board rules, such as: "We will always reorder when we get down to a 45 day supply" or "We will always carry a 60 day supply on hand and on order". It is more rational to relate reserve stock to forecast error since it is kept in inventory to protect against forecast error during replenishment lead time and today statistical sampling approaches analyzing actual data for each item can be used to determine more efficient levels of reserve stock than the intuitive approaches yielded. Considerable literature has been written on this subject in the last 10 to 15 years and the so called "Scientific Inventory Management" techniques using exponential smoothing to forecast demand during lead time and the mean absolute deviation and statistical tables to calculate reserve stock are well accepted in the universities and industry today. *Proper application* of this approach to recalculate so called "floating" order points, monthly or even weekly, can generally result in a reduction in inventory of between 20 to 40% without impairing service, or inventory can be maintained at the same level and service improved instead, where intuitive methods were previously used.

Here, then, are some useful techniques that have been greeted with great enthusiasm by practitioners and educators alike. For the practitioner, these are highly useful techniques that can enable him to make substantial improvements in his system. For the educator, they are an excellent demonstration of the potential applications of statistics and higher mathematics.

SOME OBVIOUS MISAPPLICATIONS

With all the development and writing that has been done, there have been some excellent applications of these modern techniques, but most progress carries with it some form of penalty and there has very definitely been an overemphasis on the order point type systems to the degree that some authors recognize only this type of reorder system. In the real business world, there are a good many places where these order point type systems are very inefficient ordering systems and, in many companies, serious problems have resulted from application of order points to inventories of components.

An eastern manufacturer of an electrical product applied order points to his finished inventory and to all the components that were used to assemble the finished product. Since there were many components that had common usage in many different assemblies, it was decided to use an order point system on all components and try to have the components available rather than to add the full component lead time into the order point for each finished item. This seemed to make sense on the common usage components, but generated some obvious problems on those components that were used on only one or two end items. For example, a typical end item inventory record is as follows:

END ITEM ORDER POINT = 40

END ITEM ORDER QUANTITY = 35

Week	1	2	3	4	5	6	7	8
End Item Demand	10	5	2	20	3	11	14	6
End Item Inventory	65	60	58	38	35	24	45	39

Note that with the order point of 40 and order quantity of 35, as the end item drops below order point in week 4, an assembly order is created thus generating a component demand in week 4. An assembled lot-size of 35 is received into inventory in week 7 and again in week 8 the item is once more below order point, thus creating another component requirement in week 8. This activity is reflected in the compon inventory record, as follows:

Week	1	2	3	4	5	6	7	8
Component Requirement	0	0	0	35	0	0	0	35

Using a floating order point to control this component inventory generates some interesting results. In the example shown, exponential smoothing would take the demand in week 1, smooth it, and decrease the order point. It would successively do that in weeks 2 and 3 to the point where the order point was very low and then in week 4 there would be a demand for 35. The order point would then be increased for week 5 but then the 0 demand in week 5 would be smoothed in, dropping the order point once again until another component demand occurred in week 8. Obviously, this system is 180 degrees out of phase with true component demand – and the use of a mean absolute deviation to compensate for forecast error only aggravates the problem with the result that reserve stocks are very high but components are often not on hand when they are required.

Rather than trying to use order points to make components available, it would be far more satisfactory in this case to try to forecast *when* reorders will occur and have components available to assemble at that time. Assuming that end item demand approximates 9 units per period, it can be seen that the inventory on hand in week 1 will last about 7 weeks and that the order point is approximately equal to 4 weeks; therefore, in about 3 weeks, a reorder should be expected. Since the order quantity will last about 4 weeks, assembly reorders in the future can be anticipated approximately every 4 weeks.

The components for this product obviously can be reordered much more effectively by exploding anticipated requirements down through a bill of materials. The inventory pattern for this item could be charted as shown (Figure 1), where the finished product has many small demands from customers which are "independent"; that is, they cannot be related to any known requirement, while the components of finished items tend to have a few large demands that are "dependent" upon the requirements for assembly. Using an order point on these components will tend to generate more inventory than is actually required and

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About the author –

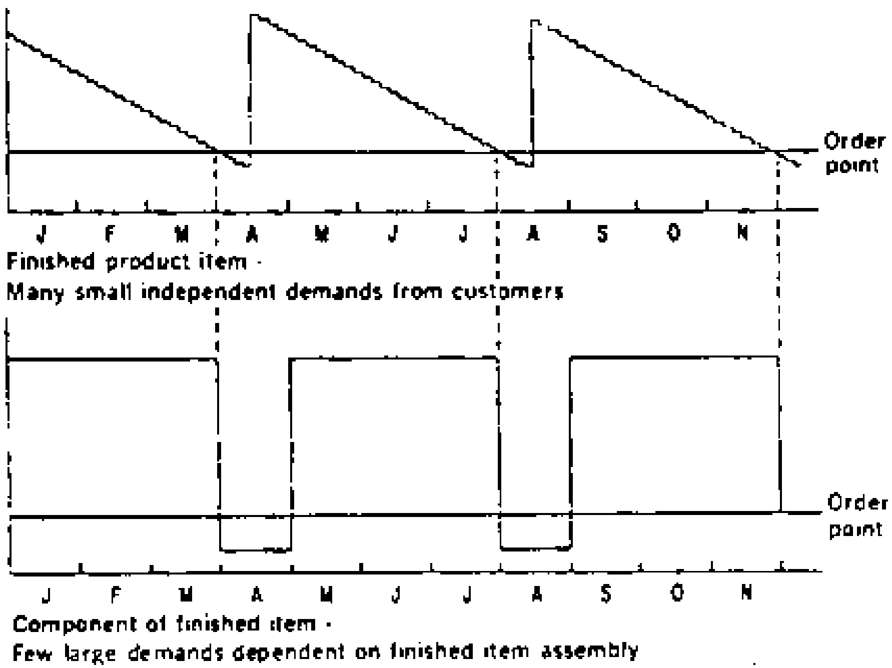
OLIVER W. WIGHT *is a partner in the firm of Plossl and Wight Associates working in management counseling and education. He is also co-author with his business partner of the book* Production and Inventory Control: Principles and Techniques, *Prentice-Hall, July 1967, now in its third printing.*

Mr. Wight was formerly Industry Education Manager, Manufacturing for IBM's Data Processing Division where he was responsible for the content of all IBM internal training and customer executive courses on manufacturing applications of the computer. Prior to this, he held positions as Staff Production Control Consultant for a multi-division corporation and Inventory Manager for a major automotive parts manufacturer.

A graduate of New England College, he has long been active in APICS educational activities and has served as National Vice President of Education and Research. He edited the recently revised APICS Dictionary.

experience in practice shows that the reverse happens too: components are often not available when they are actually needed because they are being ordered independent of the timing of end item requirements.

Figure 1. Independent vs. Dependent Demand



The very least this example demonstrates is that one universal reorder rule for everything in inventory doesn't make sense. The proponents of order point type techniques at this point may say that nothing has been proved except that the assembly order point should have included the full lead time for components used on only one end item, but that order points should still be used on those components that are used on *more* than one end item. While this example has been oversimplified, it should be readily apparent that if there were two end items using this component and each of them had an order quantity equal to an 8 week's supply, demand would be even more erratic than this example shows. An order point type system would not only tend to bring in inventory before it is needed, but at times when both assemblies happened to require the component almost simultaneously, it probably would not be available because the order point type system assumes that the annual demand will average out on a weekly basis which is not the case.

In one company where dynamic ratio type priority systems were developed. [illegible]der points were used for reordering components. The foremen com[illegible]d that many items had high priorities as soon as they were issued to the starting departments. As an example of the system's shortcomings, one foreman cited the example of a component used on two end items that was in his department with a high priority; he had checked the end items and found that there was a six month's supply of one available and that four month's supply of the other was just being assembled (with all components available). The system, because its dispatching priorities were based on an order point, assumed that each component inventory needed to be replenished as soon as it was depleted. This is the basic assumption of order point type systems, but in this case it is invalid. It would be more efficient to order components against projected assembly requirements and try to drive the inventory to zero between requirements.

A CASE STUDY IN MISAPPLICATION

Order point type techniques for components with one, or even two end uses, are not very efficient. Where, then, do order point techniques for components make sense? One proponent of order point techniques has suggested that order points can be used on any components that have more than 7 end uses. Even this is an arbitrary rule of thumb that does not work out well in practice. The following is an actual example:

A manufacturer of assembled products that are made up of many common components that must be stocked had been using intuitive order points for ordering these components. His inventory was extremely high and service was unsatisfactory so he did a study to determine whether a statistical order point system implemented on a computer would work better. Inventory simulations were run for 8 different components. They purposely chose components with many end uses and the simulations showed that a high level of service on each component would result from using an order point approach. The 8 items simulated gave these results.

NUMBER OF ITEMS	SERVICE LEVEL
2 items	100%
3 items	98.1%
1 item	96.2%
1 item	94.3%
1 item	92.4%

At first glance, this series of simulations looked very good to the company and they were only concerned that order points might not work as well on the items with less stable demand (in fact, simulations for other components with only a few end uses *did* show that a floating order point would tend to build extremely high inventories while giving very poor service).

Further thinking about the results of the simulations, however, showed that even those results that looked good on the surfact would not work well in practice. The company's service is judged by their ability to ship *assemblies, not components*. If it were assumed that this company's product consisted of only the 8 components simulated instead of the 35 to 50 components that typically go into one of their products, it might be worth asking how many times they would be unable to ship the assembly. A further check of the simulations generated the following results.

ITEM	*NO. OF WEEKS OUT OF STOCK*	*SERVICE*	*WEEKS NOT AVAILABLE*
1	3	94.3	#11, #12, #13
2	1	98.1	#52
3	2	96.2	#30, #35
4	0	100.0	----
5	1	98.1	#42
6	4	92.4	#23, #24, #35, #36
7	0	100.0	----
8	1	98.1	#19

This summary indicates that Item #1 would be unavailable in weeks 11, 12, and 13, while Item #2 would be unavailable in week 52, etc. Altogether there are 12 stockouts among the 8 items, resulting in 11 weeks (note that Item #3 and #6 are both unavailable on week #35) when the end item cannot be assembled, indicating that while service appears to be very high at the component level, it will not be very high for the assembly. In this example, while service levels for the components are as high as 100%, there are actually 11 weeks out of 52 when the products cannot be assembled, so that even for a product using only 8 components, the service level would be 78.8%.

Further examination of these simulations showed another problem that arises when components are ordered independently. It was decided to pick one week at random when none of the components were out of stock and determine how many of the end item could be put together, again assuming that it takes only the 8 components involved in the simulation. In week #15, the inventory balances were as follows:

Item #1 — 81 units
Item #2 — 719 units
Item #3 — 1134 units
Item #4 — 193 units
Item #5 — 226 units
Item #6 — 34 units
Item #7 — 87 units
Item #8 — 349 units

The simulation shows that *only 34* assemblies (the quantity of the component with the lowest inventory) could be put together in week #15, even though all components are in stock that week! Obviously, some unusable high component inventories result from this approach. As a result of this analysis, the company decided to put their bills of material on the computer and use it to reproject their requirements weekly rather than using it to improve their order points system.

The company in this example was fortunate because they used simulation to determine in advance that order points on components would not work very satisfactorily. Another company replaced a very *crude* requirements planning system with a highly sophisticated order point system for components and had disastrous results. Inventory increased 25% and there was a dramatic *reduction* in service. It's indicative of the state of the art of production and inventory control today that order point type systems, because they are well-developed in the literature, tend to be applied where they can generate very poor results indeed.

TIME SERIES MATERIALS PLANNING

Two phenomena discussed in the simulation example above contribute to these poor results:

1. *When components are ordered independently, the cumulative service level for all components will be much lower than the service levels of the individual components.* This phenomenon is one that is well known to statisticians and simply demonstrates the laws of probability in action. If an individual component is likely to be on hand 90% of the time that it is required, then any 2 components will be likely to be on hand 81% of the time (90 x 90) and any 3 components will be likely to be on hand 73% of the time, etc. Some quick calculations like those above would indicate that if the chances were 95% for any one component to be on hand and only 10 components were needed to make an assembly, the chances of all of these being available at the same time would be approximately 56%!

2. *When components are ordered independently, component inventories will not match assembly requirements well.* The upper portion of Figure 1 shows the familiar saw-tooth curve that results from an order point approach. Even for a component with many end uses and relatively uniform demand, the "saw tooths" will peak independently and thus component inventories seldom match requirements at any point in time.

The fact that those companies using order points on components *do* get some things shipped on time may seem to contradict these observations. But they usually do it by carrying extremely high inventories and doing a great deal of expediting. These expediters usually work from assembly floor shortages to try to pull the *right* item through, in spite of all the *wrong* inventory items the order point system generated.

The expediter usually has some kind of a "hot list" and in spite of the dates that the inventory system has put on component orders, he tries to get the right items to the assembly floor. He faces a dilemma with this hot list, however. If he only expedites those shortages that already exist on the assembly floor, it's obviously a case of too little too late. If he tries to anticipate shortages and expedite these, he has an extremely long hot list and the foreman's logical question is, "Which do you want first?". To do an effective job, he really needs a series of "hot lists". He needs to break down his assembly floor requirements into time periods and indicate by time period what his requirements will be. This concept extended through enough time periods to cover the component lead time is the technique called *time series materials planning*.

Figure 2. Assembly Requirements

	PAST DUE	WEEK 4	5	6	7	8	9	10	11	12	13
		—	—	600	—	—	800	—	—	400	—

END ITEM MASTER SCHEDULE

Lead Time 4 Weeks

	PAST DUE	WEEK 4	5	6	7	8	9	10	11	12	13
Projected Usage		—	—	600	—	—	800	—	—	400	—
On Hand		900	900	300	300	300					
Scheduled Receipts		—	—	—	—	—	500	—	—	400	—
Planned Order Release		—	500	—	—	400	—	—	—	—	—

COMPONENTS MATERIALS PLAN

A representative time series materials plan is shown in Figure 2. In this case, a forecast of requirements is used to generate a master schedule for the end item. Using the bill of materials for the end item, this usage is then projected against the component in the corresponding time period ... hen the inventory record for the component is referenced and an inventory balance is calculated. In week #6, the requirement of 600 will decrease the component inventory balance to 300; in week #9, the requirement of 500 with only 300 units on hand will generate a "scheduled receipt" of 500. This will then result in a planned order release of 500 in week #5 since the lead time for this component is 4 weeks and the same procedure will result in a planned order release of 400 in week #8 to cover the requirement in week #12.

This is a fairly standard approach which has been implemented in many companies using the computer. The example shown is elementary. Obviously, many components go into more than one end item and, in that case, the requirements for each end item are reflected in the projected usage for common components. Any requirements for service parts can also reflect in the materials plan. If the component used as an example has a projected usage of 50 pieces per week for service or repair parts, this could be added into the projected usage before the inventory balance and planned order releases were calculated. Lot sizes could be pre-calculated using the economic ordering quantity formula but where these usages tend to be discrete, it is often more practical to use the time series order quantity calculation. In this calculation[1], the lot sizing is done by testing to see if it is economical to combine planned order releases in order to save setups. For example, if a unit cost for the component, a weekly inventory cost, and a setup cost were provided, it would be straightforward to determine the economics of combining the planned order release for week #5 and week #8. This would result in saving one setup, but it would result in carrying 400 units in inventory for an extra three weeks. This calculation offers some significant advantages over the square root EOQ formula when calculating lot sizes for components since it tends to generate lot sizes that match assembly requirements much more closely.

Materials planning is simply a computerized approach to the requirements planning that used to be done on manually posted ledger cards. With ledger cards, it was difficult to plan requirements for a specific time period, accumulate requirements for common usage items, and recalculate these requirements as they changed. In fact, in most manual systems, this recalculation of requirements was the real stumbling block. When trying to bring all of the components together to assemble a finished product, it is essential to be able to re-explode and calculate requirements frequently as the end item forecast changes.

When punched cards were first used for materials planning, it was common to explode the end items down into subassembly requirements, post these "gross requirements" manually against a ledger card inventory balance for the subassemblies, and subtract the inventory balance to get "net requirements". These were then punched into another deck of cards representing the subassembly bills of material and exploded to get gross requirements for subassembly components. This procedure was awkward and time consuming and later inventory records were kept by the computer too so that gross requirements at each "level" could be referenced to the computerized inventory records directly with no manual intervention. With later, more powerful computers and direct access storage, it became possible to break these requirements down into fairly fine time periods to show requirements in weekly "buckets" and to recalculate these requirements as often as weekly. Today, for example, a materials plan that uses monthly planning periods and is only recalculated monthly is considered very crude.

There are basically two approaches to materials planning using the computer. One of them is a periodic recalculation or "regeneration" approach while the other technique is called "net change." The regeneration approach requires that a new schedule be completely reexploded and requirements replanned on a periodic basis, usually once a week. Some companies have found that even a weekly recalculation of requirements is not sentitive enough to changes in demand, and they have thus adopted the "net change" approach. The net change technique is designed to accept any schedule change on any end item at any time and to explode *only* this change down through the various levels of product structure to determine how it will affect component schedules. In a net change system, the computer will then generate an exception report indicating where a component schedule needs to be adjusted to meet the changed requirement.

It seems apparent, then, that materials planning techniques can be far more effective for dependent demand items than order point techniques. Actually, this is not a new conclusion. John Magee noted some years ago, "It has been found that if finished item demand is exploded into components and . . . totalled over all finished items containing the component, many control benefits can result".[2] Dr. Joseph A. Orlicky, Manufacturing Industry Consultant for the IBM Corporation, orginially developed the independent/dependent demand concept suggesting that when items are independent, such as finished goods items (where the demand of each item is unrelated to the demand for other items), it is necessary to *forecast* using techniques like exponential smoothing. Where demand is dependent (related to demand for other items), this demand should be *calculated* through a bill of materials explosion. He has further recommended, "Do *not* forecast demand when it can be calculated". Experience has shown that this is sound counsel. One possible exception is the low value common use item that may well be reordered using an order point system because it is cheaper to carry excess inventory than to use computer time to recalculate requirements.

CHOOSING THE RIGHT TECHNIQUE

Since the order point approaches are well-known and accepted in the field of production and inventory control, and materials planning has really only been introduced since the advent of the business computer, there are many common objections to the use of materials planning. Some of these are quoted and explained below:

Objection #1 – "Our experience has shown that an order point system is as good as a materials planning system for controlling component inventories."

This statement is only valid when a manual order point system is being compared with a manual materials planning system. With manual materials planning systems, the material plan can only be recalculated infrequently – in many companies, only once a quarter – and under these circumstances, an order point system could even be a slight improvement! With a modern computer system where requirements can be recalculated weekly (or even more often) and spread out in weekly time periods, company after company has found materials planning superior.

Objection #2 – "In order to give good customer service we need to use an order point system in order to have all components on hand when they are needed."

One can only conclude that those who expect statistical order points to keep components on hand have forgotten some fairly basic statistics! Most practitioners recognize that 100% service is seldom economical or attainable and, as was pointed out in the examples above, even a simple product requiring only 10 components would have only a 56% chance of all 10 of those being available at any random moment if each of the individual items had a 95% chance of being available. This type of system is doomed to fall back on expediting to get any semblance of results.

Objection #3 – "Floating order points on each component should enable us to react quickly to changes in demand."

Reaction to changes in demand could be handled much more effectively by forecasting at the end item or subassembly level. Consider, for example, an end item with a usage of 100 units per week and an order quantity of 500 units. Normally, a reorder would be placed every 5 weeks. If demand suddenly increased to 120 units per week, reorders would be placed every 4 weeks. Using exponential smoothing for this component, the system would have to recognize the increased frequency of demand, smooth it, increase the order point, and then reorder. The lag time tends to be extremely long. Using a materials planning system, if the end item exponential smoothing forecast increased from 100 to 120, this would then be reflected in the master schedule, exploded down through the bill of materials, then reflected in the *projected* component usage and planned order releases would be rescheduled. Note that the order point system must *detect* increased component demand, adjust to it, and then reorder while the materials planning system can *project* this increased requirement ahead of time.

Objection #4 – "We know we must protect against forecast error with safety stocks, so we use order points."

There is no reason why safety stocks cannot be used with materials planning. In Figure 2, if reserve stock had been set at 200 units, the scheduled receipt for week #9 would need to be 700 units rather than 500. Where there are common components that go into many end items, it is important to remember not to add all the forecast errors for all end items together when setting reserve stocks. Figure 3 shows an example based on a company that custom assembles electric motors. Their weekly forecast calls for 5000 Type "A" motors and on any one of the five different motors in this family they would like to be prepared to make 1500 units. Any component unique to motor "A" would require a 500 unit *reserve stock*, but any component used on all Type "A" motors should have less reserve stock than the *sum* of the forecast error or 2500 since it is highly unlikely that *all* motors would have their maximum demand in any one week. As illustrated only 1100 units reserve stock would be required for any component that is common to all "A" type motors. Obviously, as with order point systems, careful analysis is needed to determine optimum reserve stocks.

One more caution: since this reserve stock will now be exploded down through the bills of material, no reserve stock is needed on lower levels of inventory unless they have outside demands such as service stock.

Figure 3. Reserve Stocks For Common Components

	FORECAST	FORECAST ERROR
Motor A1	1000	±500
Motor A2	"	"
Motor A3	"	"
Motor A4	"	"
Motor A5	"	"
Total	5000 units	±2500 units

Forecast error, *all* type "A" motors = 1100 units

Objection #5 – "We have to use order points because we have so many possible combinations of components that it is impossible to forecast end item requirements."

This is usually a symptom of a problem in bill of materials structure. This problem occurs and is readily recognized in the automobile industry. It would be impossible to maintain a bill of materials for each of the possible configurations of automobiles, much less forecast them. As a result, it becomes necessary from a bill of materials structuring point of view to consider major assemblies like end items. While it would be extremely difficult to forecast the number of convertibles of a particular color that would have automatic transmissions, etc., it is possible, for example, to forecast the total number of cars, the percentage that will be a particular color, the percentage of these that will be convertibles, and the percentage that will have automatic transmissions, etc. This same problem exists in many other industries but is often not recognized. Wherever common building blocks are put together, the practitioner with good knowledge of his product structure can usually restructure his bills of material to facilitate forecasting.

Objection #6 – "We don't have time to get our bills of material straightened out so we're going to put in an order point system to get inventory under control quickly."

This can only be a stopgap. Even if order points must, for lack of proper bills of material, or lack of available computer time, be used on components temporarily, it is strongly recommended that in addition to these order points, an assembly or a matrix bill of materials[3] be used to project assembly requirements periodically, at the very least monthly, to assist in expediting the right parts through. If a computer is available, this same amount of effort put into organizing bills of material properly, product group by product group, and developing a materials planning system would generate far better, more lasting results.

Objection #7 – "There is no computer time available for materials planning in our company."

This objection is sometimes heard from people who do not have a computer; many companies that don't have computers today do their materials planning periodically with someone else's computer or at a service bureau. More often, this objection comes from someone who already has a computer in house that already is being used for many other things so that no time is available. If a larger computer is not immediately available, it would probably be profitable to send the payroll out to a service bureau and to use the computer to get the inventory under control.

Order point techniques have been given a great deal of attention in inventory control literature because they demonstrate the application of mathematics and statistical concepts, while the mechanics and applications of materials planning techniques and bill of materials structuring tend to be ignored by most colleges today because the subject is considered too "vocational". As T. M. Whitin, one of today's leading inventory theoreticians, put it so appropriately, "an increasing number of individuals are working with inventory models because they present interesting theoretical problems in mathematics . . . practical application is not a major objective, although . . . their theoretical work may be helpful in practice at some future time."[4] This is fine; we need pure research, but the fact that the literature emphasizes order point techniques should not be misconstrued: this simply means that they are most interesting from an academic point of view. The business manager's criterion is different: he must ask, "In *this application*, which technique will enable me to manage inventories better?"

Those who are considering using so called scientific inventory management techniques should consider the *principles* of statistics before applying statistical techniques arbitrarily. Statistical order point theory almost always assumes:

1. Relatively uniform average demand.
2. Gradual depletion of inventory.
3. A "Normal" distribution of forecast errors.
4. That it is desirable to have inventory on hand at all times.
5. Statistical independence of demands.

These assumptions are valid for those items which have *independent* demand, but not those having *dependent* demand. The independent/dependent demand concept is a sound guideline for application of reordering techniques: where demand is *independent* (unrelated to demand for other items), it must be forecast; where it is *dependent* (related to other items), it can be calculated. Finished goods or service parts are independent demand items while components, semi-finished items or raw materials are dependent demand items.

The practical application of the statistical approach to order points is one of the greatest advances that has been made in inventory management in the last few years. When implemented properly, where it really applies, dramatic improvements can result, but too many practitioners espouse *either* order points *or* materials planning. The professional approach to inventory management requires that we understand all of the techniques that are available to us, that we understand where they do and don't work well and that we use the techniques that will work best in each application.

FOOTNOTES

[1] See C. W. Plossl, O. W. Wight; *Production and Inventory Control: Principles and Techniques*, Englewood Cliffs: Prentice-Hall, Inc., 1967, Pg. 145-147.

[2] *Production Planning & Inventory Control*, J. F. Magee, McGraw-Hill, 1958, Pg. 90.

[3] This term is used here according to its definition in the APICS Dictionary: Bills of material for groups of products and families having common components that are arranged in a matrix so that all requirements for common components can be readily totalled. Synonym: explosion sheet.

[4] *Analysis of Inventory Systems*, C. Hadley, T. M. Whitin, Prentice-Hall, Inc., 1963, Preface.

REFERENCES

(1) Plossl, C. W. and Wight, O. W., *Production and Inventory Control: Principles and Techniques*. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1967.

(2) *MOS Inventory Management and Materials Planning Detail*, E20-0050. White Plains, N.Y.: IBM Data Processing Division.

(3) *The Production Information and Control System*, E20-0280. White Plains, N.Y.: IBM Data Processing Division.

* The forthcoming APICS Handbook will cover Materials Planning in detail.

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APICS Certification Program Study Guide
MATERIAL REQUIREMENTS PLANNING

By the Material Requirements Planning Subcommittee
APICS Curriculum and Certification Program Council

INTRODUCTION

The purpose of this Study Guide is to assist the candidate in his prepara-n for taking the Material Requirements Planning examination. The sub-t is broken down into ten topics so as to conform with the ten sessions of review course recommended for Chapter education programs. While the udy Guide is designed to be consistent with, and to complement, the review urse, it can also be used for individual preparation and study in the ab-nce of such a course.

This Study Guide is made up of the following sections:

- Description of the subject
- About the exam
- Ten sample questions
- How to use the Study Guide
- Listing of topics and sub-topics
- Correct answers to sample questions
- MRP Bibliography
- MRP film listing

MATERIAL REQUIREMENTS PLANNING

MRP, or time-phased material requirements planning, is a set of tech-iques that evolved from an approach to inventory management in which the llowing two principles are combined:

1. Calculation (vs. forecast) of dependent demand for component items
2. Time-phasing; i.e., adding the dimension of timing to inventory status data

he term "component item" under MRP covers all inventory items below the roduct or end-item level, including subassemblies, piece parts, semifinished arts, and raw materials. Requirements for end items are stated in the aster production schedule and are arrived at through forecasting, customer orders, field warehouse requirements, interplant orders, etc. Requirements for all of their component items, and their timing, are derived from this chedule by MRP.

MRP is norm[illegible] implemented via a computer-based system, because of the large amount of data handling that MRP entails. The prime input to an MRP system is the master production schedule. The overall output is termed a material requirements plan. Principal outputs are, specifically, order action (release or cancel), rescheduling of open orders (advance or defer due date), and planned (future) order releases.

Originally conceived as an approach to inventory control, MRP has been found to provide also other functions (to offer other types of use), principally priority planning and capacity requirements planning. In a manufacturing company that has inventory items with dependent demand and orders with dependent priorities, MRP represents the only sound system foundation. Other systems; e.g., scheduling, dispatching, shop floor control, and purchasing, merely execute the material requirements plan; i.e., MRP output.

ABOUT THE EXAM

The examination consists of a written test administered within a three-hour time limit. The format used is that of questions with multiple-choice answers. One hundred twenty-five items make up the exam, each item consisting of a question (or statement) plus four choices of an answer. These choices are always coded A, B, C, and D. One, and only one, represents the correct answer. The other three, called "distracters," are worded so as to appear equally attractive to someone who guesses.

All of the exam items have been developed based on a topical outline reproduced in this Study Guide. Each of the ten topics listed is broken down into a number of sub-topics, also listed. An exam item always pertains to a specific sub-topic. A sub-topic may be tested by one or more exam items, but every sub-topic does not necessarily have a counterpart exam item included in the test, which is designed merely to sample the candidate's total knowledge of the subject.

Because terminology and methods of representation within the area of Material Requirements Planning are not completely standardized, the following information is being provided to familiarize the candidate with terms and graphic conventions used in the exam.

Charts

Product structure (bill of material) relationships are being represented (Figure 1) as follows, with assembly part numbers having alphabetic, single-part and raw material numbers having numeric designations. Levels are numbered from top to bottom, starting with level zero. The quantity of component per assembly is assumed to be one (1) unless shown otherwise.

The time-phased inventory record used by an MRP system is represented, throughout the exam, in the format shown in Figure 2.

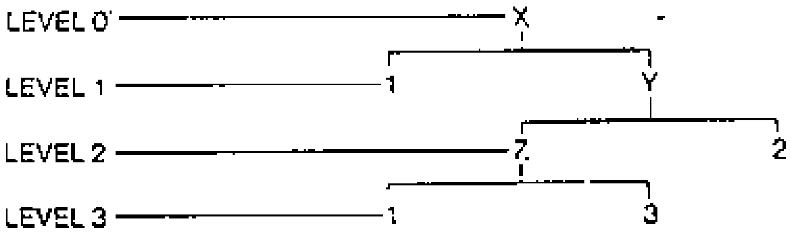


Figure 1

		PERIOD							
		1	2	3	4	5	6	7	8
Requirements									
Scheduled Receipts									
On Hand									
Planned Order Releases									

Figure 2

Terminology

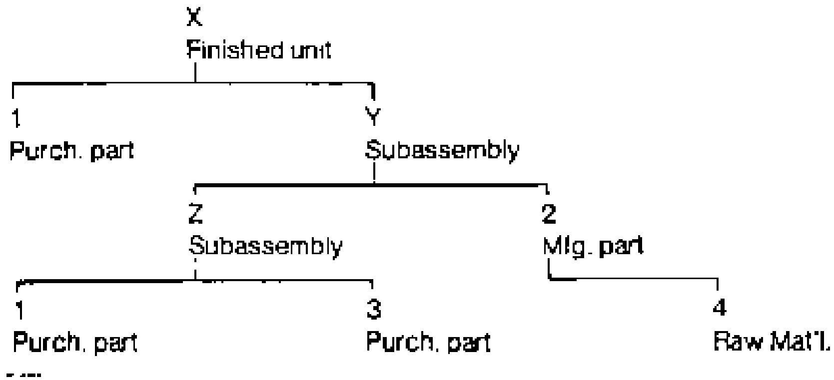
The language of the exam contains the following terms, sometimes used interchangeably, as shown:

- Bill of material processor, also bill processor
- Capacity requirements plan, also capacity requirements, load report
- Component item, also component part, component
- Date of need, also need date
- Inventory item, also item, part
- Item master (file), also inventory record, inventory (file)
- Master production schedule, also master schedule
- Material requirements planning, also MRP
- Planned order release, also planned order
- Product structure, also bill of material
- Releasing an order, also placing an order
- Requirements, also material requirements, gross requirements
- Scheduled receipts, also open orders, quantity on order
- Time period, also time bucket, bucket

SAMPLE QUESTIONS

Following are ten questions representative of the contents and format of the exam. These questions are "real" in the sense that they have been drawn from the set developed for potential inclusion in the exam. Because they are used as a sample, however, they will not be repeated in the actual exam. Correct answers with explanations are provided in a later section of this guide.

Sample Question #1.



In the example of a product structure shown, which items are considered parent items?

(A) X only (C) X, Y, Z, and 2 only
(B) X, Y, and Z only (D) X, Y, Z, 1, and 2 only

Sample Question #2

Which of the following is(are) among the uses of *planned orders* in an MRP system?

I. They may be used to project capacity requirements.
II. They are used to generate material requirements at the next lower level.

(A) I only (C) Both I and II
(B) II only (D) Neither I nor II

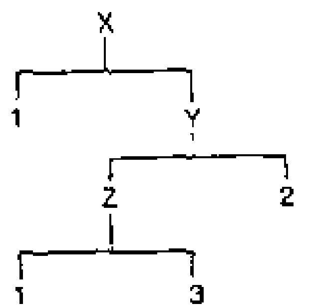
Sample Question #3

A typical capacity planning report based on orders generated by MRP has which of the following characteristics?

I. Load is leveled within available capacity.
II. Load reflects both existing and future shop orders.

(A) I only (C) Both I and II
(B) II only (D) Neither I nor II

Question #4



he product structure diagrammed, which of the following items could ject to independent demand?

I. Items 1, 2, 3, Y, and Z.
II. Item X.

(A) I only
(B) II only
(C) Both I and II
(D) Neither I nor II

le Question #5

e daily shop dispatch list will tend to rank jobs in incorrect priority ence when

(A) "C" items are excluded from the MRP system
(B) the MRP system is based on inflated lead times
(C) actual lead times vary from those used by the MRP system
(D) the capacity planning system is not integrated with the MRP system

ple Question #6

company eliminated all order points and substituted MRP, but they de the planning horizon too short. Which of the following results can be ected?

I. Orders for components tend to get released too early.
II. The usefulness of the load report is impaired.

(A) I only
(B) II onl
(C) Both I and II
(D) Neither I nor II

Sample Question #7

The MRP output that shows the source of the requirements for an item is called

(A) a priority report
(B) an input-output report
(C) a master schedule report
(D) a pegged requirements report

Sample Question #8

With Time-Phased Order Point, which of the following values must be pre-calculated before the system can function?

I. The Order Point quantity itself
II. The demand during lead time

(A) I only
(B) II only
(C) Both I and II
(D) Neither I nor II

Sample Question #9

If the Master Schedule is overstated, which of the following can be expected to result?

(A) The MRP system outputs will not be consistent with the Master Schedule.
(B) Large, unexpected sales orders can be shipped with less expediting.
(C) Shop order priorities will become meaningless.
(D) Forecast error due to product mix will be absorbed by excess inventory.

Sample Question #10

An MRP system may be ineffective in reducing the need for expediting and hot lists for which of the following reasons?

I. The system does not call for changes to released purchase and shop order due dates.
II. The system has safety lead times which vary by inventory classification (1 week for "A" items, 2 weeks for "B" items, 3 weeks for "C" items).

(A) I only
(B) II only
(C) Both I and II
(D) Neither I nor II

HOW TO USE THIS STUDY GUIDE

The key to the preparation for the exam is the list of topics and sub-topics, along with the recommended study material. The candidate should review each sub-topic listed under a given topic, and read the referenced bibliographical material. Viewing the film(s) referenced to each of the topics will help to consolidate the knowledge.

The study material is the following:

1. MRP Bibliography, November 1972 revision (see page 20)

2. Recommended reading list

MRP Bibl. #	*Title*
1	MRP by Computer
4	Structuring the Bill of Material
6	Master Scheduling
14	Net Change MRP
15	MRP Systems
17	MRP & Inventory Record Accuracy
25	Time Phasing

3. MRP film series (listed in bibliography)

4. APICS Dictionary, 3rd edition

For purposes of study, the subject of material requirements planning is broken down into the following ten topics:

- Introduction to MRP
- Fundamental MRP system functions
- Design characteristics of MRP systems
- MRP and the master schedule
- Bill of material structure
- Priority planning through MRP
- MRP outputs and their use
- Making MRP work
- MRP: regeneration vs. net change
- MRP system implementation

LISTING OF TOPICS AND SUB-TOPICS

1. *INTRODUCTION TO MRP*

Definitions and terminology
Understand the meaning of such terms as: lot sizing, planned orders, time periods, buckets, regeneration, time-phasing, priority, lead time offset.
Ref: Bibl. #15, pp.23-36

MRP vs. order point
What are the key characteristics of these two alternative systems of inventory management?
Ref: Bibl. #15, pp.3, 4, 7, 17
Film #2

Dependent and independent demand
Understand the difference between these two types of demand.
Ref: Bibl. #15, pp. 4,5
Film #2

Parent items and components
What is the relationship between such inventory items?
Ref: Bibl. #4, p. 5

Lumpy demand
What causes lumpy demand for a component item?
Ref: Bibl. #15, pp. 7, 39
Film #2

Time-phasing
What is the meaning of time-phasing as used in an MRP system and how is the data displayed?
Ref: Bibl. #15, p. 27

Inputs to MRP
What are the basic files required for an MRP system?
Ref: Bibl. #15, pp. 46, 47

The time-phased record
Understand the format and function of this record.
Ref: Bibl. #15, p. 25

Requirements explosion
Define. Understand the function of the explosion.
Ref: Bibl. #1, p. 4

Gross and net
What is the difference between a gross and a net requirement?
Ref: Bibl. #15, p. 25

Lead time offset
How is lead time offset in an MRP system and why?
Ref: Bibl. #15, p. 25

Bill of Material Processors
What are the major functions of a Bill of Material Processor?
Ref: Film #5
Bill of Material Processor Manual (available from IBM) Form #GH20-0197

FUNDAMENTAL MRP SYSTEM FUNCTIONS

Inventory item relationships
What is the relationship between inventory items found in a manufacturing company and how does MRP handle them?
Ref: Bibl. #15, pp. 37-39

Records and transactions
Understand the fields and headings in the standard MRP time-phased inventory record and be prepared to show how various transactions affect that record.
Ref: Bibl. #15, pp. 25-28, 36, 38

Feedback from shop and purchasing
What types of feedback from the shop floor and purchasing are important to MRP and why?
Ref: Bibl. #1, #15, #17
Films #3, #6

Allocation
Also referred to as an "uncashed requisition," what does that mean? What is its purpose?
Ref: Bibl. #1 (p. 35), #14, #15 (p. 47)

Planned and actual lead time
What is the difference? Which one is used by the MRP system?
Ref: Films #1, #3

Low-level coding
What does it mean and what is its purpose?
Ref: Bibl. #1, p. 5

Safety stock
How should safety stocks be handled in an MRP system?
Ref: Bibl. #1 (pp. 31-34), #15 (pp. 32-36)
Film #8

Lot sizing
Familiarize yourself with the names and workings of the various lot sizing techniques that can be used with MRP.
Ref: Bibl. #1 (pp. 30, 31), #2, #9, #15 (pp. 29-32)

Service parts and MRP
How are service parts that are also used in current production dealt with in an MRP system?
Ref: Bibl. #15, pp. 20, 26, 36, 37

Time-phased order point
How does the MRP system express an order point in a time phased format?
Ref: Bibl. #15, pp. 37-39
Film #1

MRP applicability
Where is MRP applicable, in what types of companies and to what types of products?
Ref: Bibl. #15, pp. 23-28, 37-39
Films #1, #5, #10

Functions of MRP
The three principal functions of an MRP system.
Ref: Bibl. #15, pp. 26, 28, 53
Films #1, #7

3. DESIGN CHARACTERISTICS OF MRP SYSTEMS

Level by level processing
What is it and why is it necessary in an MRP system?
Ref: Bibl. #1 (pp. 4, 5), #4 (pp. 5, 45)

Quick deck
What is the quick deck method of MRP and what are its shortcomings?
Ref: Film #7

ABC classification and coverage by MRP
Should a[illegible]s, A's, B's, and C's, be covered by an MRP system and what are the considerations in making such a decision?
Ref: Bibl. #1, p. 19
Film #7

Planning horizon
What is the minimum acceptable length of the planning horizon and why is it important?
Ref: Bibl. #15, pp. 43-44
Film #7

Time bucket size
What are the considerations in determining time bucket size?
Ref: Bibl. #1 (pp. 5, 22), #15 (p. 28)
Film #7

Frequency of replanning
How often should replanning take place to be effective and why?
Ref: Bibl. #14, #15
Film #7

MRP system effectiveness checklist
What are the key capabilities of a good MRP system?
Ref: Film #7

MRP AND THE MASTER SCHEDULE

Definition of master schedule
Describe this schedule, its format and contents.

End items
Define these items. What the master schedule does and does not include, how the information is displayed and used.

Master schedule and final assembly schedule
What are the differences between these schedules? When are they the same?

Length of planning horizon
How far out into the future should the planning horizon extend?

Developing the master schedule
How is a master schedule put together? The role of the forecast.

Unrealistic master schedule
What are the consequences?

Integrity of priorities
What is the difference between the concepts of validity of priorities and integrity of priorities? Which is related to the master schedule?

Pegged requirements
Definition and mechanics of pegging. What is the use of pegged requirements in MRP?

Customer delivery promises
How can the master schedule be used for making delivery commitments?

Ref: Bibl. #1 (pp. 21-23, 35, 36), #6, #15 (pp. 43-46)
Films #4, #10

5. BILL OF MATERIAL STRUCTURE

Function of bill in an MRP system
How is the bill used? Why is it important with MRP and not with order point?

Bill of material format
What are the standard formats for displaying bill of material data?

Bill of material checklist
What are the uses of a bill?

Item identity assignment
When must unique part numbers be assigned?

Product options
What kind of problems do they represent in an MRP environment?

Modular bills
What are they and when are they necessary?

Modularization procedure
Describe the steps involved

Pseudo-bills of material
What are they and what is their purpose?

Phantom bills
What are they? What is the reason for their use?

Common versus unique parts
Define. Which represents a problem in structuring the bill?

Ref: Bibl. #4
Film #5

PRIORITY PLANNING THROUGH MRP

Due date and date of need
Define. Why can they be different? How are they used?

Characteristics of priority systems
What should a priority system communicate? Define relative priorities.

Order priorities and operation priorities
What are the differences and uses?

MRP can keep priorities up to date
What priorities, and how does the system do it?

Dependent priorities
Vertical and horizontal dependency. How is MRP used to realign priorities?

Priority planning vs. priority control
Define the difference. Which one is done by MRP?

Complexity of priority problem, by type of company
The four types of companies that have priority problems of different complexity

Ref: Bibl. #15, #25
Films #3, #7

MRP OUTPUTS AND THEIR USE

Categories of outputs
What are these categories, and what are the specific outputs used for?

Inventory ordering
How does the system trigger order releases?

Rescheduling open orders
How does the system determine that an order should be rescheduled?

Priority control
What data generated by MRP is used for priority control?

Trial fit
Define. How is an MRP system used for this function?

MRP outputs for capacity requirements planning
What data generated by MRP is used in capacity requirements planning?

Load report
What are the three characteristics of a good load report? What does MRP contribute here?

Performance control
What measures are used to track system effectiveness?

Functions of an MRP system
What does MRP do? Where does it fit in with the overall manufacturing control system?

Ref: Bibl. #1 (pp. 11-18, 33-34), #15, #25
Film #10

8. *MAKING MRP WORK*

Inventory accuracy
Why is inventory accuracy important to the success of an MRP system?
Ref: Bibl. #1 (pp. 26, 27), #17 (pp. 1, 2)
Films #6, #11

Physical inventory control
What must be done physically in a plant to insure inventory accuracy?
Ref: Bibl. #17
Film #6

Check digits
How does the check digit work and what are other techniques used to insure accuracy?
Ref: Bibl. #1 (pp. 26, 27), #17 (p. 5)
Film #6

cle counting
hy is cycle cou g advantageous and what are some approaches to

Ref: Bibl. #17
Film #6

ys to success in an MRP system
hat are they and why is each one important?
Ref: Bibl. #15, pp. 40-54
Film #11

stem responsiveness
w frequently should replanning take place to insure an acceptable
el of responsiveness to changes?
Ref: Bibl. #14, #15, p. 28
Films #7, #9

fety stock and safety lead time
hat effect do they have on MRP in general, and priority planning in
rticular?
Ref: Bibl. #1 (pp. 9, 10, 31-33), #15 (pp. 32-36)

er responsibility
hat are the MRP user's responsibilities?
Ref: Bibl. #1 (p. 25), #15 (p. 52)
Film #11

RP REGENERATION VS. NET CHANGE

hedule regeneration
efine. What are the mechanics of regeneration? How many phases of
eration are there in a regenerative system?

atus data
hat is the difference between inventory data and requirements data?

equency of replanning
ow frequently is it practical to replan with a regenerative system?
hy?

rtial explosion by net change system
efine partial explosion. When does it take place?

Master schedule and net change systems
What is input to the MRP system under the regenerative he net
change approach?

The principle of item record balance
Describe this principle. What effect does it have on the processing
method?

The principle of inter-level equilibrium
What is it? How is equilibrium between parent and component established, maintained, verified?

Phases of operation
How many phases of operation are there in a net change system? Specify.

Allocation
Define. Is it necessary under net change?

Performance control
What kind of data for performance control does a net change system
provide: How are these data generated?

Requirements alteration
Define. How does it differ from net change? Can an MRP system be
operated permanently in a requirements alteration mode?

Ref: Bibl. #14
Film #9

10. *MRP SYSTEM IMPLEMENTATION*

Implementation phases
What are the key phases in MRP implementation?
Ref: Bibl. #1, pp. 23-25
Film #8

Study
What should a study prior to starting MRP implementation accomplish?
Ref: Film #8

Project team
Who should be on a project team which is assigned to implement MRP
and who should lead this team?
Ref: Bibl. #15, p. 52
Film #8

System design
What are the key items to consider in the design phase of an MRP system?
Ref: Film #8

Programming and testing
What can be a valuable aid in speeding up programming and testing of an MRP system?
Ref: Bibl. #1, pp. 36-38
Film #8

Supporting procedures
What procedures must be established to support an MRP system?
Ref: Film #8

Education
What must be considered in a user education program and in conversion planning?
Ref: Film #8

Conversion methods
What are three approaches to conversion and the plusses and minuses associated with each?
Ref: Bibl. #1 (p. 25), #15 (p. 25)
Film #8

The pilot system
What type of manufacturing environments will be most suitable or least suitable for the use of this method?
Ref: Film #8

Checklists
Understand the checklist of items which can evaluate the operation of your system.
Ref: Film #8

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CORRECT ANSWERS TO SAMPLE QUESTIONS

Question #1
(C) is the correct answer. (A) and (B) are incorrect because they exclude item 2, a manufactured part that is the parent of raw material item 4. (D) is incorrect because it includes item 1, a purchased part that is not the parent of any component.
Ref: Bibl. #12, p. 90
#15 pp. 24, 25
Film #5

Question #2
(C) is the correct answer. For purposes of load calculation, planned orders may be added to orders already released, so as to obtain a more complete picture of future load. Planned orders of a parent item are used by the MRP system to determine gross requirements for its component items.
Ref: Bibliography #12, pp. 49, 65
#15, pp. 25, 26, 36
Films #1, #7

Question #3
(B) is the correct answer. MRP doesn't schedule operations and doesn't use any capacity data in performing its functions. Load leveling, if done at all, would be done by another system. Because an MRP system contains information on planned (future) orders as well as open (existing) orders, an MRP user will typically take advantage of this and include both in the load calculation.
Ref: Bibliography #11 (pp. 5, 8), #15 (p. 26), #25 (p. 56)
Films #1, #3, #7, #10

Question #4
(C) is the correct answer. Independent demand, such as service part requirements, may arise for any component of assemblies X, Y, and Z.
Ref: Bibliography #3 (p. 129), #12 (pp. 29, 30), #15 (pp. 4, 5)

Question #5
(A) is the correct answer. When manufactured parts in the "C" item category are excluded, the due dates on at least some of their orders will become invalid, without possibility of correction by the system. Because they will then be incorrectly ranked on the dispatch list, the entire ranking by relative priority will become invalid.
(B) is incorrect because the fact that lead times are inflated will not invalidate the priority sequence. Priorities are based on need dates and these remain valid. (C) is incorrect because, even though actual lead times may vary, as long as the correct need date is maintained the priority sequence is

orrect. (D) is in ect, because the maintenance of valid priorities (based on eed dates) has ...ing to do with capacities or capacity planning systems.

Ref: Bibliography #12, pp. 73-76
Films #3, #7

Question #6

(B) is the correct answer. Orders for components will, if anything, tend to get released late rather than early. But there is not sufficient visibility into the future due to the short horizon, and this will reflect itself in the load report also. The usefulness of a load report depends, among other things, on being able to anticipate capacity problems far enough into the future so that there is time to take corrective action.

Ref: Bibliography #11, pp. 6-8.

Question #7

(D) is the correct answer. Pegging requirements means retaining information in the system on the sources of demand for a given item. This permits a requirement to be traced from component to parent, up the product structure, perhaps all the way to the master schedule. Answers (A), (B), and (C) are incorrect because the reports in question have purposes different from the one just described.

Ref: Bibliography #1 (p. 35), #12 (pp. 90-99), #15 (p. 36)

Question #8

(D) is the correct answer. With the time-phased order point, it is only necessary to input the forecast demand, by period, and the quantity of safety stock. The MRP logic takes it from there and arrives at the correct order point automatically. Because the order point itself need not be precalculated, neither does demand during lead time, which otherwise would be calculated in order to arrive at the order point value.

Ref: Bibliography #12 (p. 79), #15 (pp. 37, 38, 39)

Question #9

(C) is the correct answer. While the priorities will be valid, they will be meaningless for all practical purposes, because everything will tend to run behind schedule, with high priority.

(A) is incorrect because MRP outputs are always consistent with the master schedule, regardless of capacity. (B) is incorrect, in fact, the reverse will probably be the case due to overloads, the need to establish special priorities for the order, and reduced flexibility to react to the unexpected order. (D) is incorrect as there is no assurance of this at all. Excess inventory there will be, but not in matched sets required to build any product.

Ref: Bibliography #11, p. 6
Films #3, #4, #11

Question #10

(C) is the correct answer. If the system does not call for changes in open order due dates, some of these will become invalid. This will increase the need for expediting and hot-lists, to establish which orders are really needed. The same is true of a system that uses safety lead times. Shop personnel will soon learn that the due dates do not necessarily represent dates of real need, and will tend to rely on expediters to tell them what the real needs are.

Ref: Bibliography #12, p. 64
Film #3

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MRP FILM LISTING

laterial Requirements Planning Systems," an educational film series, sponsored by IBM.

lm Number	*Film Title and Speaker*
1	WHY MATERIAL REQUIREMENTS PLANNING? Oliver W. Wight and Joseph A. Orlicky
2	DEPENDENT DEMAND & ORDER POINT INVENTORY CONTROL Joseph A. Orlicky
3	MRP & SHOP PRIORITIES Oliver W. Wight, interviewed by Bruce L. Hollander
4	MRP & THE MASTER SCHEDULE Romeyn Everdell, interviewed by Robert M. Haddox
5	MRP & BILL OF MATERIAL STRUCTURE George W. Plossl, interviewed by Richard P. Chynoweth
6	MRP & INVENTORY RECORD ACCURACY George W. Plossl
7	WILL THE REAL MRP SYSTEM PLEASE STAND UP Joseph A. Orlicky
8	MRP IMPLEMENTATION CONSIDERATIONS Walter E. Goddard, interviewed by Thomas P. Putnam
9	NET CHANGE MRP Joseph A. Orlicky, interviewed by Paul J. Rosa
10	MRP OUTPUTS & HOW TO USE THEM L. James Burlingame, interviewed by Robert E. Downhill
11	DIAGNOSING THE SICK MRP SYSTEM O[illegible] W. Wight

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SEMINARIO SOBRE PLANEACION DE REQUERIMIENTOS DE MATERIALES

MATERIAL REQUIREMENTS PLANNING BY COMPUTER

SEPTIEMBRE, 1978.

I. The Workshop and its Participants

Introduction

One of the most difficult problems facing business managers today is the challenge of learning from the experience *of others.* This can at least avoid repeating others' mistakes and, at best, can save months of work in achieving results; particularly in the field of inventory and production management, where developments have been rapid and the "body of knowledge" is increasing at an almost explosive rate.

A willingness to exchange information on management and technical subjects has been characteristic of American business. Hence the popularity and success of seminars, conferences and workshops conducted by technical societies, trade associations and others. Much of APICS' success in assisting practitioners in the field has been achieved thru gatherings of those who are doing something well and those who want to find out how to do something better in their companies. Of necessity, these sessions are intended for large audiences with varied backgrounds and different interests, cover a wide range of subjects and can give in-depth coverage to only the most basic techniques.

Because of the great interest in "Material Requirements Planning" and the major improvements yielded by its successful application, a two and one/half day workshop was organized to bring together representatives of some of the companies now successfully using the technique and those sufficiently advanced in implementing new computer programs to have met and solved most of the problems of designing a sound system.

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ACKNOWLEDGEMENT

This Special Report was prepared and edited by two men well-known to APICS, George W. Plossl and Oliver W. Wight. They have been active as members and as chapter and national officers for many years.

Their writings, individually and combined, are familiar to readers of APICS *Production and Inventory Management Journal* and cover a wide variety of subjects in our field. They have talked, alone and together, at almost every Chapter in the continental United States including several abroad, and have contributed their efforts at APICS' chapter, regional and national conferences.

Oliver Wight edited the Society's first Seminar Chairman's Guide and the Dictionary. George Plossl edited the Bibliography and now heads up the Committee developing the Curricula and Certification Program. Both have edited chapters in the new Production and Inventory Control Handbook. Together with Jim Harty, they prepared the first Special Report on Managing Lot Size Inventories.

They see education and professional development as the real job of the Society. In their opinion, each member who helps APICS helps himself even more. It is their hope that other Special Reports on the vital topics in our field will follow soon.

Henry F. Sander
Executive Director

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Why a Special Report?

[illegible] enthusiastic reaction to this workshop by the participants resulted in their agreement that the sponsors, Plossl and Wight Associates, should prepare and offer its proceedings in an APICS Special Report as the best means of making this information available to others interested in this vital subject.

II. Requirements Planning and Related Techniques

A. Introduction

There are two basic methods for determining when to issue a replenishment order for an item in inventory. One is to establish an "Order Point" or "Minimum" based on past actual or forecasted future usage and to re-order this item whenever its inventory drops to or below this order point quantity. This method assumes reasonably *uniform usage* in *small increments* relative to the replenishment lot-size and that it is necessary to *initiate replenishment* action *immediately.* Mathematical techniques and statistical analyses have been applied to improve this technique through better forecasting and better means for calculation of safety stocks. There is a wealth of literature on this method and several computer manufacturers have programs available to speed up its implementation. Many companies have attempted, without real success, to use this method to control *all* classes of items in inventory.

The second basic method is to calculate requirements for sub-assemblies and parts (collectively called "components") based on the needed quantities of the higher-level assemblies, usually finished products, in which they are used. Demands for the finished product assemblies are determined from forecasts, backlogs of orders or both and modified by existing inventories to prepare a "Master Schedule" of production requirements by time periods which provides the input to "Material Requirements Planning" to determine component needs.

Requirements planning approaches have been known to practitioners for many years. It was extremely tedious to calculate requirements manually for components of complex assemblies; it was virtually impossible to re-explode requirements frequently enough as schedules changed using a manual system. With the advent of the computer, requirements planning became a practical inventory control technique. The type of requirements planning discussed in this report, the multi-period or *time series requirements planning* (sometimes called "time-phased") is really practical only with a computer in most companies with broad, diversified product lines. The pros and cons of requirements planning vs. order point have been debated for some time. One of the workshop topics – the independent/dependent concept – discusses this further.

B. Description

Figure No. 1 shows the typical requirements plan in simplified form. The *End Item Master Schedule* for the assembly is the input that starts the plan; it schedules 600 assemblies in Week 6, 800 in Week 9 and 400 in Week 12. One very crude approach to requirements planning (called *quick deck*) merely "exploded"[1] the end item requirements into the corresponding quantities of components and ordered these components to arrive in the same time period. In the example shown in Figure No. 1, this would result in ordering 600 sets of components in Week 6, 800 in Week 9 and 400 in Week 12, thus ordering *gross requirements* without considering available inventories. Overcoming this makes the *level by level* requirements plan more complicated; it must take the requirements for the finished assembly, post them as *gross requirements* against the component inventory record, and then project the available component inventory balance in the time periods to show when this inventory will have to be replenished. The example in Figure No. 1 shows a gross requirement of 800 in period 9, a projected on-hand balance of 300 in period 8, and, therefore, a *net requirement* (scheduled receipt) of 500 that will be needed in period 9. Since the lead time is 4 weeks, the planned order must be released 4 periods (the *lead-time offset*) earlier. That means that the order for 500 should be released in period 5.

ASSEMBLY REQUIREMENTS

	Past Due	Week									
		4	5	6	7	8	9	10	11	12	13
		—	—	600	—	—	800	—	—	400	—

Component Materials Plan

Lead Time 4 Weeks

	Past Due	Week									
		4	5	6	7	8	9	10	11	12	13
Projected Requirements		—	—	600	—	—	800	—	—	400	—
Projected On Hand		900	900	300	300	300					
Scheduled Receipts		—	—	—	—	—	500	—	—	400	—
Planned Order Release		—	500	—	—	400	—	—	—	—	—

Figure 1

1 APICS Dictionary, Second Edition defines "explosion" as: "an extension of a bill of materials into the total of each of the components required to manufacture an assembly or sub-assembly quantity."

If this component were used in other assemblies, their requirements would be posted also on the *projected requirements* line of the plan. Service or spare parts requirements for the component would also be posted on the projected requirements line to get *total* planned usage. If this component were a sub-assembly that used other parts, its *planned order releases* would be posted to the inventory records for these parts as projected requirements. *Planned orders at one level generate gross requirements at the next lower inventory level.*

Time periods in requirements planning are often called *buckets;* each bucket requires a field in the computer file to store the data applicable to that time period. Most requirements plans use weekly time buckets and undergo a "time shift" when updated. In the example shown in Figure No. 1, the current period is evidently week 4; next week, the current period will be week 5. Anything that is not acted upon at the proper time will appear in the "Past Due" column. For example, if the planned order for 500 units were not actually released in period 5, a quantity of 500 would appear in the past due column of the requirements plan in Figure No. 1 when period 6 became the current period.

There are two basically different approaches to requirements planning: *regeneration* and *net change*. Regeneration involves actually discarding previous plans and starting over every week with a new master schedule, exploding it into component requirements, netting against available inventories and developing new planned orders. Net change, on the other hand, explodes only changes from the previous master schedule down through the bill of materials until a component is reached which is unaffected by the change.

Depending on the complexity of the product structure, there will be a number of "levels" in the bill of materials. The end item itself is usually designated level 0, assemblies and sub-assemblies which make it up are level 1, their components are level 2, etc. The computer must recognize the *lowest* level of any bill in which a component appears so that it will accumulate requirements from *all higher* levels before netting against any component's available inventory. Identifying and maintaining low-level coding is a difficult but necessary activity in requirements planning.

It is frequently desirable to identify a requirement with the higher-level component which triggered it. Called *pegging*, this really amounts to a partial where-used listing which identifies, in more or less detail, where requirements come from.

C. Format

There are alternative ways to present data in a materials plan like Figure No. 1; each company tends to adopt its own conventions. "Projected Requirements" is sometimes called "Gross Requirements", "Planned usage" or "Forecast" and sometimes includes separate lines for different types of demand (assembly requirements from higher levels, service or spare parts needs, interplant requirements, etc.) "Projected On Hand" may be called "Available Inventory";

present on-hand balances may be shown in the header space (like "lead time" in Figure 1) or in the Past Due Bucket (used simply for convenience). Quantities "allocated" to meet specific demands from orders released for higher-level components, assemblies or products are usually deducted from the present on-hand balance and may also be shown in the header space. Safety stock quantities may also be deducted from such net available balances *prior* to entering them on the "On Hand" line, or the netting shown in future periods can compare On Hand with the safety stock quantity instead of zero to determine when a net requirement exists.

Some companies show orders as *Scheduled Receipts* only when the planned order has been released. Some add these quantities to the on-hand available balances, others do not, preferring to show a projected negative balance so that the planner will recognize that the material is "on order" and not in stock.

The format of a requirements plan can be tailored to a company's own desires. Superficial differences should not be allowed to obscure the similarities among the systems used by different companies.

D. Lot Sizing

Today there is an almost bewildering variety of lot-sizing techniques available. The best known is the Camp square-root formula: $Q = \sqrt{2As/I}$ where Q = the "economic" order quantity; A = forecast annual demand, dollars; s = ordering cost, dollars; and I = inventory carrying cost, decimal fraction. This formula is adequately covered in the literature [2] and needs no further explanation here.

A basic assumption of this formula is that usage will be at *uniform rates*. For components of an assembled product, the requirements tend to be anything but uniform; they usually occur in discrete "lumps", principally because of lot-sizing at the higher levels. Typical component requirements could be 500 pieces in Week 1, 800 pieces in Week 7 and 1100 in Week 18, for example, with nothing required in other weeks.

For this item, the economic order quantity calculated using Camp's formula might be 1500 pieces. After using the 1300 total for Weeks 1 and 7, the balance of 200 would have been useless inventory since it is insufficient to meet Week 18's needs. After running another 1500 to fill this requirement, a balance of 400 will be carried uselessly until the next requirement appears. The square-root approach does nothing to balance out the pre-determined lot-size with the actual requirements.

There are several *discrete lot-sizing* approaches which attempt to overcome this problem:

1. Lot-for-lot ordering - the lot-size at the assembly level is exploded down through all sub-assemblies and components without any further lot-sizing at intermediate levels.

2 "Production and Inventory Control: Principles and Techniques" - Plossl & Wight, Prentice-Hall, 1967, Chapter 4.

2. Period Order Quantity (POQ) - the lot-size is expressed in terms of periods of supply, calculated as follows:
   a. Using the forecast annual usage for the component, calculate the EOQ using the square-root formula.
   b. Divide the EOQ quantity into the annual usage to determine the number of reorders per year.
   c. Express the order quantity in "time periods covered" by dividing the number of reorders into 52 for "weeks" or 12 for "months".

Whenever a new order is to be placed, the computer looks ahead the number of periods specified by the POQ and adds up their total requirements to determine the lot-size. The lot-sizes will vary as the requirements change; however, since any individual EOQ is valid over a broad range with only small cost increases, this approach is more likely to give real economies than one which results in carrying small residues of lots which serve no useful purpose for long periods.

3. Discrete Requirements or Time Series EOQ — when usage occurs in discrete "lumps" at irregular intervals, the square-root EOQ assumption of uniform usage is violated. Components of assemblies will experience such intermittent, irregular usage; seasonal products will also show fluctuating usage. For these conditions, lot-sizing involves minimizing carrying plus ordering costs by combining requirements for several periods in one lot.

   Two basic methods of making such calculations are:
   a. Least unit cost — based on determining what combination of requirements for successive periods yields the lowest *cost per piece*.
   b. Least total cost — seeking the lowest *total cost* involved in ordering and carrying combinations of requirements for successive periods.

Appendix I is a reprint of "Dynamic Order Quantities" by Thomas Gorham, published in the First Quarter, 1968, issue of Production and Inventory Management, APICS Journal. This article illustrates the application of each of these methods. The author's conclusion, based on many simulations, is that the least total cost method yields significantly lower inventory and ordering costs. This is substantiated by simulations run at Black & Decker and other companies.

As discussed in Appendix I, these techniques have the same objective as the square-root formula — "balancing" ordering and carrying costs to produce the *minimum total cost*. They use the ratio of ordering to carrying costs (S/Ic), called the "economic part-period" factor since it defines the quantity of parts carried for a number of periods which will make the total carrying cost equal to the ordering cost, thus the most economical situation. The names "Part-Period Balancing" and "Economic Part-Period Ordering" have been used by computer manufacturers in their software programs to describe the *least total cost* approach to discrete lot-sizing.

S[illegible] planning periods (i.e., weekly instead of monthly), since they deal with smaller requirements, improve the technique's ability to get *closer to the best* balance between ordering and carrying costs.

IBM's Production Information and Control System (PICS) program for requirements planning contains a modification of part period balancing, called "look-ahead[illegible]look-back", intended to improve the lot-sizing. This feature attempts to extend the horizon farther into the future, in effect considering not one but two successive lot orderings. The following example illustrates how the "look-ahead" feature works:

Period	1	2	3	4	5	6	
Net Req't	85	220	176	143	435	81	
Lot Size	481			659			without "look-ahead"
Lot Size	624				New		with "look-ahead"

Using a value of *S/Ic* equal to 600, part-period balancing would set the lot size to be produced in Period 1 at 481 pieces, covering requirements in Periods 1, 2 and 3; a new order would be needed for requirements in Period 4 and beyond. Looking ahead, however, the large requirement in Period 5 would be carried in inventory during Period 4; it may be more economical to include the 143 Period 4 requirement in the preceding lot and start the new lot in Period 5. This is determined by checking the cost of carrying 143 pieces for 3 periods (produced in Period 1, used in Period 4; equal to 429 part-periods) against carrying 435 pieces for 1 period (produced in Period 4; used in Period 5, equal to 435 part-periods). Since the former alternative is cheaper, the lot size in Period 1 would be increased to include the 143 pieces for Period 4 as shown and a new lot run in Period 5. The following example illustrates the "look-back" feature:

Period	1	2	3	4	5	6	
Net Req't	435	143	200	88	99	104	
Lot Size	778			New			without "look-back"
Lot Size	578		491				with "look-back"

Using the same value of S/Ic, part-period balancing would set the lot size for Period 1 at 778 pieces, calling for a new lot to be run in Period 4. The "look-ahead" feature would not change this decision. Looking back from Period 4, however, the large requirement of 200 in Period 3 will be carried for two periods; it may be more economical to start the new lot in Period 3. This will be true if the requirement in Period 4 (88) is equal to or less than one-half that in Period 3 (200). The "look-back" feature would thus change the lot size in Period 1 to 578 pieces and start a new lot of 491 in Period 3 to cover Periods 3, 4, 5 and 6.

The look-ahead feature should be tested first and look-back employed only if look-ahead leaves the lot-size unchanged.

Since [illegible] increasing demand will satisfy the look-ahead feature, inflate lot-sizes [illegible] destroy the proper balance between ordering and carrying costs, an[illegible] should be made to be sure the last requirement in the lot, when con[illegible] alone, is less than the economical part-period value. In the above example, look-ahead would *not* have changed the original 481 lot-size if the part period value of Period 4's requirement (3 x 143 = 429) had exceeded 600. Since it did not, look-ahead acted.

Part-period balancing utilizes these features to extend the planning horizon and test alternate decisions involving relatively large requirements to see if economies are possible. Their value in real-life is discussed in the Workshop Topics Section 8 – Lot-Sizing in this report.

4. Wagner-Whitin Algorithm – this is a more precise mathematical solution well-known in academic and operations research circles (See "Dynamic Version of the Economic Lot-Size Model", Management Science, Vol. 5, No. 1, Oct. 1958). No one at the workshop knew of any companies using this technique.

E. Safety Stock

There are three basic alternatives for providing safety stock in a requirements plan. They are:

1. Adding "safety time". If, for example, the components to make an assembly are needed in Week 10, their replenishment orders are scheduled to come into stock in Week 9, thus putting one week of "safety" time into the plan.
2. The top level input in the master schedule can be increased or over-forecast. For example, if the planned requirement in one period is for 10 units of a given product, but orders could be received for as many as 15 units, 5 extra sets of parts could be planned as safety stock.
3. Demand variation could be measured at the component level and a safety stock calculated for the component, using statistical order point methods.

Putting in safety time really doesn't tell the system the truth and can be particularly harmful if the safety time is varied for different items (i.e., one week on A components, two weeks on B components, three weeks on C components, etc.). Priorities are distorted and by such cushions, work-in-process inventories are inflated and operating people soon learn that they have more time to get parts than the due dates indicate. The resulting "credibility gap" can easily offset the benefits of having safety allowances.

Overforecasting the top-level demand can pyramid the inventory of components common to several finished products. The maximum projected demand for each top-level product will be exploded down to the level of such common components. Since it is extremely unlikely that actual demand will equal the maximum for *all* top-level items *simultaneously*, the requirements for common components will be overstated. An excellent solution to this problem developed by one company is covered under the Workshop Topics Section 9 – Safety Stock.

F. The Independent/Dependent Demand Principle

Dr. Joseph A. Orlicky, Industry Consultant to the Manufacturing Industries Marketing Department of IBM suggested in 1965 the independent/dependent demand principle which defines as "independent" such items as finished goods for which it is necessary to *forecast* demand using statistical techniques like exponential smoothing or other forecasting approaches and then establish an *order point* or *minimum* to trigger a re-order when the inventory is reduced to this level. Demand is "dependent" when it can be *calculated* through a bill of materials explosion based on the forecatted demand for the top-level independent items. He recommended, "Do *not* forecast demand when it can be calculated". The principle states that inventories of finished goods items and service parts not used in current assembly (*independent* demand items) should be replenished using order points, but that requirements planning should be used for all components going into higher level assemblies and for semi-finished material (*dependent* demand) that is later converted into many different items.

	J	F	M	A	M	J	J
ASS'M A	10	10	10	10	10	10	10
SUB B	20	0	20	0	20	0	20
PART C	40	0	0	0	40	0	0

Figure 2

Figure No. 2 indicates why the independent/dependent demand principle is valid. In each of the months January through July the demand for Assembly A is steady at 10 per month. The assembly is made in lots of 20; therefore, demand for sub-assembly B will be lumped into requirements of 20, 0, 20, 0, etc. The sub-assembly is made in lots of 40; therefore, demand for Part C will appear as requirements of 40, 0, 0, 0, 40, 0, 0, etc.

This example illustrates a situation involving a part and a sub-assembly which are used only in one higher-level item. It has been said that the demand for components will be much less erratic and lumpy if as few as seven higher level items use it. The fallacy of this in most companies making assembled products can be verified by examining records of actual usage of such components.

Romeyn Everdell, principal, Rath & Strong, on numerous occasions has noted that the literature of inventory control is obsessed with *quantities* (order quantities and order points), but, once lot sizes are introduced at any level, the question of *timing* becomes much more significant than quantity. Because it clearly identifies timing, time-phased or time-series requirements planning will do a better job of ordering dependent demand items than an order point technique which only implies timing, based on *average* usage where averages really are inappropriate.

III. Participating Companies Case Studies

A. Introduction

Figure 3 gives a quick synopsis of important factors for those participating companies that were doing Requirements Planning and some significant features of their plans.

A few of the columns on the report require a little explanation. "Experience in years or months" means the amount of time the company has actually been using requirements planning to control their inventory. "Make-to-stock or order" tells whether the company is manufacturing the finished, assembled product to a forecast or whether they are ordering parts to a forecast and assembling the product after receipt of customer order. "Type computer" where IBM is indicated means System 360; the column indicates the model (IBM 40, for example, means IBM System 360, Model 40). The only exception to this is Data-Control Systems' IBM 1130, a small scientific machine not part of the 360 series. Only one company had a different make computer – Dictaphone with a Honeywell 1200.

Dictaphone used the Honeywell Bill of Material Processor but chose to write their own requirements planning program. Black & Decker, Perkin-Elmer and Twin Disc all wrote their programs long before the IBM PICS package was available. Data-Control Systems wrote their own because they have an IBM 1130, for which no requirements planning software is currently available.

B. Case Studies

1. Black and Decker

The Black and Decker Inventory Status printout Exhibit IA* shows a typical time series requirement plan; one page per item is printed out. Black and Decker has approximately 23,000 components with five levels in the product structure. The fields are all well defined on Exhibit IB. It is interesting to note that this is a net change, and, therefore, an exception type program. Inquiry into inventory status is also available via visual display terminal. The bottom block entitled "status" contains all the detailed pegging information. Later in the text of this report examples of Black and Decker's handling of master scheduling and engineering change provide further information about their requirements plan.

* Exhibits referred to in the case studies appear as foldout material in the center portion of this publication.

Company	Company Size (1)	Experience in Years or Months	Make to Stock or Order	Regeneration or Net Change	Pegging - Yes or No	Number of Time Buckets	Size of Bucket in Weeks	Lot-Sizing	Frequency - Daily or Weekly	Type of Computer		Remarks
Black & Decker	L	3 Y	S	N	Y	52	1	Lot for Lot	D	IBM 40		Very advanced system; eng. change especially good.
Data Control Systems	S	1 Y	O	R	Y	16	1	POQ	W	IBM 1130		Simple - doing the most with least.
Dictaphone Corporation	M	6 M	S	R	Y	56	1	POQ	W	H 1200		Basic system - (2) uses "capacity planning" fields.
General Railway Signal Company	M	2 M	0,5	N	Y	130 (3)	1	PPB	W	IBM 40		Uses IBM PICS package - much modified.
Mackee Corporation	S	6 M	O	R	N	52	1	EOQ	W	IBM 30		First known user of IBM PICS.
New Britain Machine Company	S	3 M	0,S	R	N	36	1	PPB	W	IBM 30		Uses IBM PICS, Mechanics Hand Tools Division
Perkin-Elmer Corporation	M	4 Y	S	N	N	11	1	POQ	D	IBM		Original System designed for has worked well. New System operating on 360.
Twin Disc, Inc.	M	3 Y	0,S	N	Y	100 (4)	1	EOQ	D	IBM 30		Incorporates Inquiry features

(1) – Large = over 75 million sales; medium = 26–74; small = under 25.
(2) – See Dictaphone case study.
(3) – Printout only shows 48.
(4) – Printout only shows 51.

Figure 3

Data-Control Systems

The Data-Control Systems Material Requirements Plan Exhibit II is probably one of the simplest and easiest to read. Note that there are four parts shown on one report. Since most of the material is purchased, a 16-week horizon has been adequate although a longer one would be very desirable. The actual on-hand balance ("3" for Part AD 011430) is shown in the "Past Due" column. This is simply a matter of convenience; obviously, the amount on hand cannot be past due. The other figures that might be shown in that column include Allocation, On Order and Planned Order, all of which *could* be past due. In the first example there are 3 on hand, 3 on an order that is past due and 15 on order due in the current week. If the orders are received, the On Hand balance will rise to 21 as shown.

In the next week there is a requirement (Data-Control Systems calls this "forecast" – it actually could be forecast or actual customer orders since theirs is an assemble-to-order type business). On the printout below the Planned Order line there are two product numbers, 231 and 237, identified as "Items in Forecast". These are the products in the master schedule which are actually causing requirements. This is a simple "pegging" or "live where-used". Note that the "Messages" row at the top shows "AA" indicating an open order in past due condition. Note also that this is the "Purchasing Copy" (top right hand corner). Purchasing can see from this requirements plan that the past due order for 3 Right Rails, part #AD 011430, is really needed this week to cover requirements next week. Purchasing can also see that the balance of 15 on order due the current week are actually needed by week 04/25. When a vendor is having trouble getting parts in on time, it's most helpful to have accurate priority and delivery information available.

The third part, AD 011433, VCO Board, illustrates an interesting situation. The message "BB 05/16" indicates that the projected on-hand balance (16) will be below the desired safety stock level (17) in week 05/16 and that an order should be planned to be released five weeks (the lead time) earlier. The computer printout doesn't show the quantity of the planned order to be released in week 04/11 because there is already an order for 35 that is due in week 05/23. This tells the inventory planner that the system knows it should create an order based on the projected on hand balance in week 05/16, but it also recognizes that there is already material on order due in a later time period; the planner must decide whether to release another order or reschedule the existing one.

For part AD 011451, Front Panel, the "55" under "M.W.R." means "more work required" to make these available for use. This panel is usually kept in stock unpainted and the "Stock Balance" reads zero. The total on hand is considered to be 55 and this is what is used in the requirements plan since painting lead time is very short.

Data-Control Systems shows "Allocation" also, indicating the quantity on an order released to the storeroom but not yet picked. It represents an "uncashed requisition". Note that allocations are shown in time periods rather than in one header field so that time values can be assigned to them.

The Data-Control Systems report then shows pegging, the use of analysis to generate exception messages and a simple, basic format that is user-oriented. The large margin on the left hand side of the report is used by the planner to make notes about what he is going to do. His supervisor can then review these notes to see what action is planned.

3. Dictaphone

The Dictaphone Materials Plan Exhibit III is a weekly regeneration system using weekly time buckets. Two items are shown on each printout page. Several things are significant about this very basic and useful report which clearly defines each of the major fields.

It shows six past-due time buckets. In the real world there are always fall downs and having six past-due time periods enables Dictaphone to give relative priority to past-due items. It also shows single level pegging. Part #1154-000 Ball Steel is at level 03 and the next higher assemblies in which it is used are shown. These are the two items that have created requirements for this ball steel. The materials plans for these two items would show what the requirements cover if there is any question about whether or not an order needs rescheduling, cancellation, etc.

Dictaphone also uses exception messages. A rescheduling flag such as an "E" (early) or "L" (late) flag is shown on released orders (see week 053) when the due date deviates from the required date by more than an acceptable variance. This alerts the planner to situations which require rescheduling.

Capacity planning information is also shown in the inventory record. The critical starting machine center and the set-up family code for manufactured parts are printed in the header. This enables the planner to level input to key starting work centers; he can also group items to release orders to minimize set-up by combining "families" of items which can be run on screw machines, for example, with a major set-up and minor alterations. Dictaphone does not add "Orders Due" to "Available". Note that the available balance on the Ball Steel in week 067 shows as 297- and has not taken into account the 10,000 on order due in week 053. Most companies add in actual released orders when projecting the on-hand balance but do not take into account planned orders.

4. General Railway Signal Company

The General Railway Signal Requirements Planning Status Exhibit IV is very similar to that used by Black and Decker. There is one item per page and detailed pegging is used. Blank lines are provided at the bottom for the planner to write in the action he wants to take. It is interesting to note that few report formats provide such convenient space for this type of notation. Obviously it is very useful to the planner and to his supervisor.

General Railway Signal utilizes IBM's requirements planning package substantially modified through the use of exits to include an open transaction and order master disc file in lieu of the subordinate item master record. The Order Master file contains data concerning an order such as vendor name code for purchase orders, customer name code for shipping orders, routing for factory orders, etc., and the address of the first transaction in the Open Transaction file, thereby providing the capability to start randomly the retrieval of all open transactions on a given order. The Open Transaction File, which is organized in part number sequence, contains individual transactions representing requirements (forecasts, shipping orders, undelivered components of open factory orders and planned requirements generated by Requirements Planning), open factory and purchase orders and planned orders generated by Requirements Planning. Each open transaction contains a transaction code (requirement vs. open order, etc.), schedule date, quantity, order number and the address of the next item in the order chain used for the retrieval of open transactions. Conceptually, these files provide a capability similar to the Bills of Material file; components of an assembly can be retrieved randomly from either file.

The GRS program contains one-level, detailed pegging shown under "Drawing Number of Next Level Due In". Open orders are rescheduled automatically for most items; manual rescheduling is used for certain top level items with special codes. GRS uses "requirements alteration", a net change approach using the IBM PICS package. The basic IBM package doesn't provide the capability to change the schedule of planned requirements if there has been a lead time change or to substitute the planned requirement of the deleted Bill of Material component for the new component. GRS has written programs to provide these capabilities.

GRS has also modified the IBM program so that they can print a projected available balance, shown as "PAB" under the net requirements section. The GRS program shows the amount of modification that can be made to the IBM PICS program to tailor it to an individual company's requirements.

5. Markem Corporation

The Markem Corporation Requirements Generation Exhibit V is a fairly straightforward use of the IBM PICS program with only minor modifications. The major change made was to include a projected on-hand "Balance", intended primarily to provide information for rescheduling. This enables the planner to determine quickly the time period into which an order should be rescheduled. An exception notice that the order should be rescheduled is one of the available IBM PICS exception messages. To make it easier to read the report, Markem has added a number sign (#) after an open order quantity and an asterisk (*) after a planned order quantity. This is illustrated by part number 0282301, which has an open order for 80 pieces due in week 634 and a planned order for 80 pieces in week 644.

Input to Requirements Generation is at the finished product level and is based on the build schedule for the assembly department. Many of Markem's parts have service usage in addition to assembly demands. They maintain a running average forecast of service requirements which is added to gross requirements at the part level.

Markem was the first company to use the IBM PICS package. It has been highly successful and they have been particularly pleased with the improvement in their ability to get parts to the assembly floor on time and reduce their dependence upon expediting.

6. New Britain Machine

The New Britain Machine Company Hand Tools Division installed a very straightforward application of the IBM PICS packages including Inventory Control, Bill of Material Processor and Requirements Planning. The only change made was to add a "Planned Receipt Line". Their's is a weekly plan with thirty-two future weeks and four past-due weeks as shown on Exhibit VI.

Input to the Master Schedule comes from three sources: statistical forecasts for end product tool sets based on exponential smoothing; special promotions with the dates forecast by New Britain or by their customer; and make-to-order items with due date specified by the customer.

Allocations are divided into those needed to meet customer orders and those for manufacturing orders for stocked items. Several codes are used to indicate various lot-sizing techniques employed and the safety stock approach to be used. Lead time is expressed in working days. As can be seen from the Exhibit, demand is very lumpy due primarily to large promotions and lot-sizing of tools at the higher levels.

To avoid distorting statistical forecasts by inadvertently adding orders related to promotions, New Britain has built in a "filter" which tests all order quantities against the previous forecast average and rejects those which exceed the average by more than a fixed percentage. They have also included raw material for forgings made by one of their suppliers in their bill of materials structure so that they can furnish to the vendor an estimate of his raw material requirements.

By a very concentrated effort, New Britain was able to install these programs in slightly more than six months. While no significant modifications to the PICS packages were made in the original installation, New Britain is now working on the addition of a projected "On Hand Balance" to the printout and also on pegging requirements to the higher level item generating them.

*7. Dodge Manufacturing Corporation**

Dodge has also used the IBM PICS programs with relatively few modifications. As shown on their Material Requirements Plan Exhibit VII, they have added the "Net Available" and show both "Planned Orders" indicating the receipt date and "Start Planned Orders" indicating when orders should be released. They use weekly time buckets with one past-due bucket and eighteen weeks of data printed out although the system has fifty-two weeks of data stored in the computer. Lead times are given in working days.

Input to the plan originates from an annual forecast updated monthly by the Marketing Research Department and converted to a manufacturing "Program" to adjust finished goods inventory levels. The program data is spread evenly over the weeks or entered in seasonal patterns by the computer. Customer orders for non-forecasted items are scheduled in the weeks required. Fixed lot sizes are used. It can be seen that the quantities on released orders (shown on the "On Order" line) are added to "Net Available" but planned orders are not. This indicates to the planner that this material has not yet been ordered and he cannot count on it to satisfy requirements.

Another interesting feature of the Dodge report is the handling of exception messages. For each item, the number printed on the "Exceptions" line is the code included in the PICS package. For item 018240, for example, the exception "06" indicates that a net requirement exists for some period and an open order exists in a future period. Repeating the 06 four times indicates that the condition exists in four weeks (8/10, 8/17, 8/24 and 8/31) where a net requirement was not filled although an order (for 1000) was due to come in later (week 9/07). This provides all needed information for the planner on one sheet, making it unnecessary for him to search separate listings for exception reports to determine what actions he might have to take.

Dodge has done an outstanding job of designing a very legible and useable form. By printing only eighteen weeks they are able to get five item reports on a single sheet thus minimizing paper work and speeding up review for planning and ordering decisions.

8. Perkin-Elmer Corporation

Perkin-Elmer is one of the most experienced users of requirements planning, having been one of the first to install it over four years ago. Their original system was designed around the file limitations imposed by second generation equipment and used four-week time periods. These caused a great many problems but they were, nevertheless, very satisfied with the improvements made possible. They have recently installed their newest requirements planning system which uses weekly time periods. Exhibit VIII shows the Planning Status Report produced in the latest system. The plan includes two past-due weekly periods, ten future weekly periods and ten monthly periods beyond. The "Sales Plan" is exploded requirements coming down from the master schedule for higher level sub-assemblies, the "Export Plan" shows requirements from other plants outside of the continental United States and the "Other Plan" generally means service requirements.

* Installed since data in Figure 3 was tabulated.

rkin-Elmer has pegged requirements, orders and allocations and are using a net change system. In addition to the regular printout they have inquiry capability via visual display units and exception reports analysing the status of an item and recommending action on it.

Requirements and other data are kept in the computer in weekly time periods even though they are printed out in monthly groupings beyond ten weeks. The objective here, of course, is to reduce the amount of paper being generated. There is little handicap with this approach since precise reaction to changes in requirements is available during the immediate future time periods and not so necessary in distant time periods.

9. Twin Disc, Incorporated

Twin Disc has 33,000 parts with eight levels. They use a net change type system with exception reports only. Their Material Status-Production Schedule report Exhibit IX is straightforward and requires little explanation.

Twin Disc embodies much of the latest thinking in their requirements plan. They show not only total planned orders but also, on the line below planned orders, exploded requirements for actual customer orders. This enables them to distinguish between requirements to meet forecast demand and requirements for firm customer orders. Requirements for actual customer orders are also combined into a "fail safe" expedite report which identifies parts that are urgently needed to make shipments to customers. Twin Disc shows the "Lower Level or Critical Part" required for a particular assembly, identifying the part in short supply that could keep the assembly from being built. They also peg upward, showing the "Model Used On".

While not shown on the Exhibit, one of the features of the Twin Disc program for purchased items is to show on the printout the prime work center in the vendor's plant where the item would be made. This enables them to combine requirements for all items made in each prime work center and "buy" capacity from the vendor without firming up actual part orders. When attempting to reschedule one item they can also see what other items might be rescheduled to help the vendor improve delivery of the urgent material.

Twin Disc, like Perkin-Elmer and Black & Decker, are very experienced in using requirements planning. They are thoroughly satisfied with their program. Its simplicity even with the refinements included in the system, make it noteworthy.

IV. Workshop Topics and Discussion

A. The Independent/Dependent Demand Principle

The participants in this workshop could be expected to have some bias in their opinions on whether or not the independent/dependent demand concept was valid, since they are either using or developing programs applying requirements planning for control of their dependent items. On the other hand, each has had experience using order points and will continue using order points where they apply. It could well be argued that others who have *not* had experience using both techniques are in the weakest position to judge which works better in specific circumstances. The concensus of these users strongly supported the independent/dependent demand principle and they could find no reason to question its validity.

One company recently started using requirements planning on most dependent items but kept some of their multiple-use items on order points. They found that the order point items gave them the most trouble in meeting assembly requirements; they intend to extend the requirements plan to include these items in the near future. Another company put their low-value "C" items on an order-point type visual control, omitting them from the requirements plan. Each week the inventory of these components is visually reviewed for reordering. They have had no significant problems with this approach.

Some of the more experienced companies using requirements planning believed that low-value items would not require the same amount of attention from the planner because of infrequent ordering and that they would be better controlled when included in the requirements plan. In one instance, inventory transactions are not posted for low-value items but their requirements are exploded down through the bill of materials to be sure the order points reflect current usage rates. One of the problems in handling low-value items with the visual review or a similar simplified order-point type system based on historical usage is the possibility of an engineering standardization program changing the application of a component and increasing its usage drastically.

In general, these companies seemed to feel that requirements planning was justified on low-value items, since lack of these items could cause an assembly line shutdown. On the other hand, the cost of requirements planning in terms of the computer explosion time or file storage required might make it necessary to exclude low-value items from the requirements planning program, in companies that have limited computer capacity.

B. Benefits.

In reply to the question of whether or not the introduction of requirements planning generated benefits, the group's answer was an overwhelming "yes". Results can be found in four primary areas:

a. Reduction of component inventory levels.
b. Improvement of customer service.
c. Reduction in product cost, principally direct labor.
d. Reduction in inventory and production control personnel.

Four companies using requirements planning for considerable periods of time have been selected as indicative of the benefits possible; to avoid revealing confidential information, they are not identified by name. Company A has increased inventory turnover (based on inventory and sales at cost, not including finished goods) from 2.9 to 4.5; customer service improved about 6%; product cost effects have not been documented; the number of people in inventory and production control is essentially the same, but their work has been upgraded to include many analysis and control procedures not possible previously.

Company B has reduced component inventory by 1/3; service has improved slightly; there has been no significant change in product cost or in the number of people in production control.

Company C has reduced inventory by 22%, service is up approximately 20%; product cost is essentially unchanged; the number of people in inventory control handling the ordering of components has been reduced 35%.

Company D has reduced component inventory by 1/3; the number of late orders (this is a make-to-order company) has been reduced 90 to 95%; the cost of the product is down 7%; indirect labor including truckers, production and inventory control personnel, shipping, receiving, stores, etc. has been reduced by 25%; although payroll costs did not go down 25% because many of these people, particularly stockroom personnel, were upgraded substantially.

The justification of a requirements planning system will obviously be different for each company. When a new system is installed in a dynamic environment, results are not easy to document. Specific improvements will depend to some extent on the effectiveness of the system being replaced.

The results from putting a system of this type in are also likely to be different for each company, depending on many factors. One company known to the attendees has a number of experienced personnel with a high degree of product knowledge doing a simplified manual job of requirements planning, pulling orders in the stockroom early, developing shortage lists from these and expediting effectively to get needed shortage items. This is effective because of a fairly stable product line and the presence of experienced planners with product knowledge developed over a period of fifteen years. The introduction of requirements planning in this company probably would not achieve great improvement. It may be necessary, however, in preparation for the day when products become too complex for manual requirements planning or when the planners currently doing the job have been promoted or retired and replaced by less experienced people.

Potential benefits are considerably greater in some companies. With certain types of products, for example, assembly labor costs can often be reduced substantially when component availability is improved and it is unnecessary to build around missing components or borrow components from other assemblies.

Long computer running time is frequently cited as a major drawback of requirements planning. Most companies have no programs now running on their computers capable of producing even a fraction of the potential benefits of requirements planning. One participant pointed out intangibles that can come from requirements planning. Benefits from improvement in morale because more parts are available and better performance by planners to whom the system makes more sense are hard to measure. Less expediting and less need for informal sub-systems have built the confidence of everyone in his company.

In general, requirements planning by computer is not difficult to justify. In fact, because it is fairly easy to demonstrate adequate payback, goals and objectives may not be set nearly high enough. Many specific savings and improvements may thus be overlooked and no effort made to achieve the full results the system is capable of producing.

C. Master Scheduling.

Nothing much has been written on this subject, yet it is the key to requirements planning. The master schedule, usually for level 0 assemblies, is the basic input to the requirements plan. A *new* master schedule is used periodically in a *regeneration* system; *only* the *changes* are entered in a *net change* system. The master schedule for every company represented at this workshop consisted of both forecasts and firm orders. At Black & Decker, the manufacturing group has no responsibility for finished product inventory; this belongs to the marketing group. Manufacturing receives a forecast of requirements by product one year in advance for capacity planning purposes.

Each month the products in the 27 – 31 week time bucket are reviewed and "authorized", that is, the requirements become firm from a Marketing standpoint and manufacturing can begin spending money to satisfy them.

The requirements in the 13 – 31 week buckets can be changed rather easily upon mutual agreement between Marketing and Manufacturing. If less than 13 weeks from assembly, manufacturings investment is greater and changes are not agreed to as readily. At a point 8 weeks from assembly, Marketing is required to finalize lot breakdown, and from this point, changes are possible only if extra-ordinary demands occur.

At Twin Disc, level 1 sub-assemblies are forecast. Actual orders for finished products coming into the system are checked against sub-assembly availability: if enough material is on hand or on order for receipt in time, the order is entered for delivery as requested by the customer. If not, the order is scheduled in a later time period; it can be reviewed, however, and the system overridden if later developments indicate a chance of getting the material through to meet the customers requirement. The master schedule uses the forecast or total of actual orders, whichever is larger, in each time bucket. If a sub-assembly had a forecast for ten units and customers orders were received for six, the master schedule would use ten units; if actual orders required twelve, this higher total would be used.

The blending of forecasts and actual orders is done manually in the majority of companies; a few do it partially by computer. The latter require rules like, "Use forecast or actual, whichever is larger, except in the first eight weeks of the plan use only actual orders". This is based on eight-weeks lead time for the product and assumes that no orders will come in during the eight-week period requiri hipment in less than normal lead time. Obviously, this time period will change m company to company and there will be frequent cases in many companies where it will be desirable to have orders shipped in less than the normal lead time.

The participants made a strong recommendation that care be taken to avoid the pitfall of letting master schedule requirements fall back into a past-due period at the time shift. For example, when a forecast doesn't materialize, the difference between actual orders released for assembly and the forecast could be considered a past-due requirement. This would then explode down through all levels, generating requirements for sub-assemblies and parts that would not actually be needed when scheduled. There should not be any "past-due" quantities in the master schedule itself unless these will really be used *in addition to* the regularly scheduled components; this requires considerable care and attention to developing the master schedule.

One topic discussed in detail was whether or not an assembly should be rescheduled when a component shortage occurs. A purchased component, for example, could be scheduled by the vendor for delivery some weeks after it is required. The consensus was that this assembly should be rescheduled so that all common components would be freed up for use elsewhere and also to avoid giving high priority to components not actually needed. The conclusion of most of the participants was that anytime a component that is not required is being worked on, it is probable that a component that is really required will be pushed aside.

What is the best size of time bucket for a materials plan? Those people who had considerable experience using requirements planning indicated that a weekly time bucket seemed preferable. The group could think of very few applications where a shorter time period would be justified or necessary.

It's important to take capacity into account when developing the master schedule. Obviously, assembly capacity will limit the master schedule; putting more material into the master schedule than can actually be assembled will only inflate component inventories, generate larger shortage lists and achieve no good results *unless* assembly rates are to be increased to utilize the excess components.

Black & Decker has developed a ratio of parts fabrication hours to assembly hours. They determine from the finished product forecast the assembly hours required and apply this ratio to determine parts fabrication hours required to cover requirements for service parts, part orders from other plants and accessory requirements. If actual plant capacity is exceeded, they negotiate with Marketing to reduce the assembly and/or accessory requirements. Components are then scheduled to meet available capacity.

Who makes the forecast on which the master schedule is based? At Black & Decker this is done by the Marketing Department, at Twin Disc it is done by Production Control using historical data and exponential smoothing. At Data Control Systems, the forecast is made by the Materials Manager with some help from the Marketing Department. Everyone agreed that, in theory, the marketing department should make a heavy contribution to the forecast used in the materials plan; there were many instances, however, where marketing did not assume much responsibility for realistic forecasts and the responsibility for developing a valid master schedule fell on production and inventory control people alone. Whether marketing is involved in forecasting or not, it was agreed production control people should be responsible for developing the official master schedule.

D. Conversion to Requirements Planning.

The basic files needed to do requirements planning on a computer are:

1. The item master (inventory) record.
2. The product structure (bill of material) record.
3. The master schedule.
4. The open order file.
5. Back order file.
6. (Optional) The allocation file.

Typical item master records are shown in many computer manuals. One of the most widely circulated is *The Production Information and Control System Manual* E20-0280, available on request from IBM Data Processing Division, 112 East Post Road, White Plains, NY 10601. Other computer manufacturers have similar information available. One significant and critical omission from typical item master records is information needed to control release of work to the factory. The traditional approach is to have the inventory control system generate orders regardless of the plant's capacity to handle them and then let production control or plant people worry about how to get them through. Today, it is becoming widely recognized that lead time control requires levelling out the input of work, at least to starting departments where it is most easily controlled. This requires some orders to be released early and the task of identifying such items is easy if the item master records have in them some reference to the key machine group or starting work center each item goes through. Information should be included in the item master record on:

1. The key starting department.
2. The key machine group.
3. Set-up time.
4. Standard hours of running time.

Obviously, key machine groups are not always the first operations ("cutoff" or "rough grinding" could be the first operation although the "turret lathes" are the key machine group and could be the second or later operation). While such information is included in shop routings it is desirable not to have to reference the routing file before determining whether the order is actually going to be released or not.

The product structure file is also well covered in the literature. The master schedule file generally isn't; it would contain the information discussed in Section C – Master Scheduling. The open order file contains pertinent data on open purchase or manufacturing orders (not customer orders), indicating quantities and time periods in which they will be available for requirements planning.

Assembly often can be started even though one or two parts that go into the product at a final stage of assembly are missing and some companies release such orders. In the absence of a well-designed allocation procedure, *because the requirements for these parts will not be included with those exploded down from the master schedule now that the assembly order is released, a back order file must be created.* Data from this file is entered into the plan at the *component* level to show that a requirement still exists. "Allocation", covered later in Section L, can mean many things and is difficult to handle correctly; the back order file is simple and straight-forward.

The following topics are the ones the group felt most strongly influenced successful conversion to a requirements planning system:

1. Be sure that bills of material are complete and accurate. Check, double-check and triple-check them. Any part not included on a bill of material won't be ordered. Using the bill of material as a picking list and checking all unplanned stockroom transactions was suggested as an effective way of insuring bill of material accuracy.
2. Eliminate inventory record errors and keep records accurate. Just taking a physical inventory is not enough; true record accuracy requires developing disciplines and security so that all transactions are properly recorded. There is a need for a "Zero Defects" approach in this area, since operating an effective requirements plan places greater demands on inventory record accuracy. Only by this means can excessive inventories, heavy expediting and ineffective informal sub-systems (like physically laying out parts in advance of assembly needs) be eliminated.
3. Teach people how to develop the master schedule properly. The first inclination of schedulers accustomed to other systems is to use the computer simply to generate a giant shortage list.
4. Be sure to *tell* the master schedule *the truth*. The importance of this was emphasized by all participants. When lead time "cushions" are inserted or the master schedule overstated, the plan will "lie back to you" by developing unnecessary orders. One company had serious problems with their requirements plan because they used as a master schedule the finished product *shipping* schedule rather than the sets of parts they would withdraw from the stockroom for bulk assembly preceding final assembly and shipment. The master schedule must reflect *the quantities of components to be pulled from the stockroom* in each time period for assembly.

Conversion to requirements planning was generally made very cautiously. A few of the companies began requirements planning on a pilot basis on one product line before going to all products. They felt strongly that they would not do it any other way because of the problems involved in testing the system and training people. The majority of the companies started requirements planning on all product lines simultaneously because they had difficulty isolating one product line for piloting purposes.

It was emphasized that the fewer the things that are changed, the easier the installation will be. Dramatic changes in lot-sizing, for example, should not be introduced simultaneously with the conversion to requirements planning. Every effort should be made to minimize the number of potential problems and to prevent unrelated upsets which might bias people against the program.

Companies which had recently started requirements planning experienced a large number of reschedules of open purchase and manufacturing orders. New Britain Machine indicated that half of their open purchase orders were rescheduled out well beyond the normal lead time. At Dictaphone, information in the item master record on key operations helped generate the right advance orders when the inventory system indicated no requirements for some critical work areas in the plant.

Everyone emphasized the need for training and participation on the part of the users. New Britain Machine, for example, prepared typed sample requirements planning sheets and reviewed in detail with the planners how they would use such information well in advance of computer output. *The requirements planning-system does not control inventory, people do; they must understand the system if they are to use it intelligently to make better decisions.*

One of the questions discussed was the number of planners needed to review requirements and initiate action. The most that any company had was six; the fewest was two. There seemed to be no correlation between the number of parts, the number of levels to the assembly or any other measurable number. It depends more on the type and number of decisions being made; a company requiring extensive review of engineering changes through their requirements plan will need more personnel than a company not needing as much control effort. As cited previously under Section B – Benefits, most companies found they could achieve the desired control with reduced planning personnel or greatly improve control with the same number of people.

One point obvious from this group was that in every case the user of the system had full responsibility for designing and installing requirements planning. In no case was a consulting firm used for anything but occasional guidance and advice (as opposed to having resident consultants design the system) and in no case was a systems group within the data processing department primarily responsible for the systems design; this responsibility was always assigned to the users.

E. Stock Status Records and Stockrooms

Sound requirements planning depends on accurate inventory records more than the common "order point plus expediting" system. With order points, the informal systems of pulling parts early to find shortages, etc., really control the inventory (see discussion on page 24, numbered paragraph 2). It is imperative therefore, that specific steps be taken to make and keep inventory records accurate. These successful companies summarized the dramatic changes needed in their stockrooms, recognized as the source of most record errors:

1. Stockrooms were locked so that the stores supervisor could assume responsibility for and really control both paperwork and material flows.
2. The importance of stockroom control was recognized by top management; in one case the president himself set the example by insisting that even he be among the non-authorized people excluded from the stockroom.
3. People in the stockroom have been upgraded in pay and status; their prime responsibility has been defined as "maintaining accurate records" — "proper care and handling of material" has been made secondary.
4. Adequate sub-systems have been set up to insure that engineers, product service people and assembly foremen, who may need parts when stockrooms are not manned can be serviced but adequate paperwork records will be maintained. One company not represented at the workshop has set up a separate open stock area with a few of each component to fill such needs.

There was general agreement that tight stockroom discipline is vital and that record accuracy will probably never be completely satisfactory. Counting errors, for example, cannot be avoided and audits of record accuracy through cycle counting will still have a small percentage error, particularly on low-value items, which must be tolerated.

One common error, especially where parts look very much alike, occurs when the wrong item is pulled from the stockroom bins. Assemblers or shop people who find the error later may simply hold the parts for future use and draw the correct parts from stores. Alternatively, they may return the incorrect parts while withdrawing the correct ones. In either case an unplanned transaction occurs and these are most difficult to control to prevent errors. Unlike counting errors which make only one record wrong, identification mistakes will cause *errors* to occur in *two* records, one for the part actually withdrawn and one for the part which should have been picked. To minimize this problem, Larry Sheley, Inventory Manager at Data Control Systems applied an ingenious check-digit technique. Check digits can be calculated in many ways; one of the most common is the Modulus 10 method, used on many credit cards to detect errors in account numbers. Using this method, a check digit is calculated as follows:

Assume that the part number is *138209:*

Step 1. Starting with the right hand units digit and proceeding from right to left, double every other digit, ignoring intermediate digits and handling carryover quantities exactly as in normal multiplication.

1	3	8	2	0	9
	6		5		8

Step 2. Insert the original digits that have not been doubled:

1	6	8	5	0	8

Step 3. Add these digits. Total = 28

Step 4. Subtract the units digit (8) of the sum from 10 to obtain the check digit.

10 – 8 = 2

Part number, including check digit is then 1382092.

Data Control Systems has calculated a check digit for each of their part numbers. That digit appears on the bin separate from the part number. When the stock man picks material from a bin, he writes the check digit on the requisition when he posts the quantity withdrawn. The check digit normally doesn't appear on requisitions or on the master parts list that he would use to make out a requisition for an unplanned transaction. When the part number is keypunched, a check digit is calculated by the machine and compared to the digit that was on the bin. If these do not coincide, an error is indicated and immediately followed up to determine what happened and get the record corrected. Data Control Systems concludes this has reduced the number of part identity mistakes by better than 90%.

To control unplanned transactions, Data Control Systems gives the supervisor of the stockroom a copy of the requirements plan. If someone in the plant requests material indicated as available on the requirements plan, he can issue it. If there are planned requirements against that material, the requester must obtain the approval of the inventory planner before the material can be released.

F. Bill of Material Structure

Most of the companies represented at this workshop had satisfactorily structured their bills of material and were no longer concerned with the problem so this was not a major topic. In at least one company, sales statistics are maintained for Level 0 assemblies. It was recognized that forecast accuracy is less than it would be if they based it on history of Level 1 assemblies because of the tremendous number of Level 0 assemblies made from a relatively few at

Level I.

Most of the companies represented did not try to maintain bills of material for Level 0 items. Their bill of material records covered the major sub-assemblies but not the top level assembly since, in most cases, the product shipped to the customer is quite modular and an almost infinite number of Level 1 combinations is possible.

Some of the companies have carefully structured their bills so that the common components used in many bills of material are grouped under a "kit" number so that the individual components appear only once. The unique components are combined with the kit number to make up the actual bill of material used to manufacture the end product.

A bill of material in a computer system doesn't have to represent an actual sub-assembly; it can represent a set of parts to be combined with other components to make a true assembly. This approach can make forecasting more accurate since the common component "kit" will tend to have more stable demand than the many sub-assemblies that use these components in combination with many unique components. "Kits" can also reduce the work of maintaining bills of material files for engineering changes, shorten computer processing time, reduce the storage space required in the product structure file and simplify the calculation of safety stock (discussed later in Section I – Safety Stock).

Fisher Controls structuring problem typifies that of any company whose product is extremely modular, sold in very small quantities per order with thousands of individual orders received each week. In a single product line the number of combinations of valve bodies, gaskets, springs, fittings, pilot valve assemblies, etc., could give them well over a million possible final product configurations. It is extremely unlikely they will sell some of each of the possible configurations just as automobile manufacturers are unlikely to sell every possible combination of transmission, body, radio, engine, etc., that could be made. Trying to anticipate which bills of material are required to describe likely combinations is an impossible task.

Using the technique of "superstructuring", they have developed an order entry matrix that allows them to specify the end product by calling out of the system bills of material of the modules at Level 1 needed to put together a valve assembly meeting their customer's specifications. The result actually is a unique bill of material for each order. In one product line alone, restructuring their bills of material to include only Level 1 assemblies and putting common parts on a separate bill of material to avoid repeating them throughout the product line has resulted in reducing the number of bills of material from 288 to 48 and the number of product structure records from 8,640 to 335.[1]

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1 "Stop: Before You Use the Bill Processor," Dave Garwood – Production & Inventory Management – APICS Journal, 2nd. Q., 1970

G. Engineering Change Control

All participating companies recognized the need for good control of engineering changes as necessary to maintaining accurate bills of material and minimizing inventory write-offs for obsolete material. The problems become more acute when using requirements planning because the bills of material are a vital element of the planning system in addition to describing how the product is put together.

Black & Decker has a well-designed and operated engineering change control system under the direction of an Engineering Change Coordinator, reporting to the Inventory Manager. Changes are classified as:

E (immediate) – to be made as soon as tooling, purchased components and physical ability of plant permit.

E – to be made as scheduled, tied to a specific order for finished product.

P – to be made at the convenience of Manufacturing, to achieve minimum cost and obsolete inventory.

For all but E (immediate) changes, the ECN (engineering change notice) number is linked to a specific order for finished product in a time period in the computer. A weekly engineering change analysis program in the computer checks to determine whether planned finished product requirements have actually materialized; if not, the ECN "effectivity date" or "fence" is moved ahead or back to make the best use of available components.

Twin Disc utilizes an ingenious approach to handle the timing of optional changes. If Part A is a single-item component replaced by Part B in an engineering change, B is set up in the bills of material of all products using A. The system is told that "A is made from B" and the lead time and order quantity for "A" are set at zero. As requirements planning explodes a master schedule to determine total demands for A, available quantities of A will be used up. When gone, net requirements for A will trigger gross requirements for B, a clear signal indicating the time period in which B will be required and that A should be deleted from bills of material.

If A is a sub-assembly made of several components, B is chained into the bills of material as the item from which the component having the *lowest available* quantity is made. The system then calls for B only when all possible quantities of A have been assembled and used.

Twin Disc's is, therefore, a *quantity-based* control, compared to Black & Decker's *time-based* control. The Emerson Motor Division of the Emerson Electric Company uses a "phase in / phase out" control similar to Twin Disc's where feasible; in other areas, they use a tie-in to a specific manufacturing lot, like Black and Decker.

Companies having experience with engineering change control programs emphasized the need for intelligent human direction. The deeper they got into such programs, the more obvious it became that questions relating to disposition of obsolete parts, rework possibilities, tooling availability, vendor capabilities, quality and other factors could not be programmed into the computer.

H. Lot-Sizing

The consensus of the group was that "part-period balancing" with the "look-ahead / look-back" feature is over-sophisticated. Theoretical economies may be possible using this technique, but the forecasts and cost estimates that go into the calculation hardly justify the pseudo-precision that such techniques appear to produce. In addition to this, the group felt that the difficulty in giving a clear explanation of the look-ahead / look-back feature to inventory planners might well offset any potential benefits. One of the principles of system design recognized by the participants was, "Make the logic obvious" and this was violated by the look-ahead / look-back feature. The least total cost or part-period algorithm without look-ahead / look-back appears more reasonable. Most of the experienced companies had modified even this technique in their programs. Only two companies were using the full technique and did not have sufficient experience to draw firm conclusions. One other used part-period balancing but imposed a ceiling of eight weeks' supply on the lot sizes. Two companies used Period Order Quantities; the rest used fixed lot-sizes, modified by purchase discounts and shop restrictions.

Using pre-determined lot sizes in a requirements plan tends to generate lots that do not match component requirements. This problem was discussed in Section D – Lot Sizing. In addition, a small increase in requirements at the top level can generate an order for a full lot size and as this generates other orders down through the levels of sub-assemblies and parts, it can result in a greatly amplified demand.

Using any dynamic lot-sizing technique, even POQ or square root EOQ recalculated with requirements planning, poses some serious problems. The problems relate to rescheduling orders and are demonstrated by the following example:

1. At Level I the requirements plan generated a planned order for 1000 units, the lot-size of the sub-assembly. This gross requirement generated a net requirement for 1000 at Level 2 and a manufacturing order was released to the shop for 1000 on which work was started.
2. The following week requirements at the top level are changed; as a result a dynamic lot sizing technique recomputes the lot size at Level 1 and changes it from 1000 to 1150. The problem is what to do about the open order for 1000 of the Level 2 component?

   Dynamic lot sizing at Level 2 might even combine this requirement with other Level 1 requirements to set a much larger lot-size than is needed to cover the 150 additional, all based on lot-sizing economics.

The company with the longest experience with Period Order Quantity verified that recalculations of lot sizes on a dynamic basis did create a number of emergency orders and was a serious problem. The problem is simply stated — dynamic lot sizing at one level can properly combine and recombine *planned* orders, but, if actual orders have been released, dynamic lot-sizing "economies" at Level 1 can create very heavy additional rescheduling costs at Level 2. To avoid this problem, this general approach was recommended:

1. At the top level, use a fixed order quantity. If requirements change, vary the *timing*, not the order *quantity*.
2. At intermediate levels, order one-for-one. This is generally acceptable, since sub-assemblies' set-up times tend to be very low.
3. At the lower levels of the bill of material use as a discrete lot-sizing technique such as POQ or Least Total Cost. Since these will be exploded down to a few lower level items, mainly purchased raw materials, the rescheduling problem is minimized.

Another potential solution to this problem is to determine for an inventory item the cumulative lead time down through all its lower levels and, as much as is practical, use the rule: "No planned order within cumulative lead time can have its quantity changed". No one is using this approach, but it sounded feasible to the group.

Only one conclusion emerged clearly from this discussion — that dynamic lot-sizing techniques were easier to develop and program than to use in the real world. Most of the more sophisticated techniques have yet to prove that they make possible real-life benefits.

I. Safety Stock

Of the three approaches to setting safety stocks discussed in the workshop (see Section II – Safety Stock), none appeared to be fully developed as yet. The objections to using "safety time", lying to the system, inflating work-in-process, etc., have already been stated. This approach should be used very judiciously, if at all.

The third method, an interesting new approach, was being tested by New Britain Machine Company, measuring requirements variations at critical component levels to set statistical safety stocks like those used with order points. They had not yet had sufficient experience to draw firm conclusions, but early indications were not promising.

The second method had the most practical application. Statistical analysis of demand variation can be made at the end product level. Forecast error can be determined and safety stocks related to the probability of meeting a given total demand. For example, if end item (or Level 1) demand averages 10 units per month, analysis of forecast error may indicate that only 10% of the time will demand exceed 15 units. A 90% service level goal would then require 5 units of safety stock, and 15 units would be entered into the plan for the current month with ten units in each succeeding month.

Increasing the top level input by "over-forecasting" in this manner seemed to be the most practical approach but it introduces the problem of avoiding pyramiding safety stocks of common components. Assume, for example, three assemblies A, B and C with demand forecast and error as indicated:

Assembly	Forecast	95% Service Forecast Error
A	10	3
B	20	7
C	15	5

There will be no problem with unique components going into these assemblies; they will have safety stock requirements exploded down to their level only for the assembly in which they are used. For example, 3 sets of unique components should be ordered to protect against demand in excess of forecast for Item A. The safety stock for a common component going into Assemblies A, B and C would be 15, however. Since the maximum demand for all assemblies is extremely unlikely to occur simultaneously, 15 units of safety stock of common parts would be excessive.

A formula widely used in quality control to handle "interference fit" problems arising from the cumulative effect of tolerance variables, known as the "square root of the sum of the squares", can be applied to this problem also. Using this formula, safety stock for a component common to Assemblies A, B and C would be calculated as follows:

$$\text{Safety stock} = \sqrt{(3)^2 + (7)^2 + (5)^2}$$

$$= \sqrt{9 + 49 + 25} = \sqrt{83}$$

$$= 9 \text{ units}$$

This formula is being used in an off-line, periodic calculation by Data Control Systems to determine safety stock quantities to be planned for common components. Use of this formula has enabled them to reduce safety stock investment by about 40% with no reduction in service. Another company intends to calculate the safety stock in this way, but to add it to the next order quantity outside the system so that safety stocks will not generate new requirements at lower levels.

It is important to note that many companies do overforecast but do *not* recognize the safety stock quantities separately. By doing this, they will get excessive quantities of safety stock on common components. It is also important to note that with this approach, safety stock should be carried at one level only. For example, if safety stocks of sub-assembly "a" are calculated this will automatically generate safety stocks for the components going into "a" and no further safety stocks should be calculated. If parts going into sub-assembly "a" have additional direct usages in assembly A, B or C, the safety stocks for these requirements would be carried at the parts level.

Much work remains to be done to perfect this most promising technique for calculating safety stocks. Effects of lead time and lot-size on service levels have not been explored but the technique while approximate is practical and appears superior to other approaches.

Obviously, safety stock has to be used with great caution in requirements planning. The basic idea is to get as precise a date as possible on an order and to update it through periodic recalculation. Requirements planning also permits inventory to drop to zero between requirements. Adding safety stocks will tend to defeat both of these capabilities and should be done only after careful analysis and with clearly defined benefits.

J. Rescheduling and Priorities

Figure 4 shows a rescheduling problem with a requirements plan. Following the ordering rules given it, the computer has found that the projected On Hand Inventory will drop below the Safety stock level of 17 in Week 6, requiring a planned order to be started in Week 1. Checking further, it finds that there is material already on order and due in Week 7. Data Control Systems uses the double asterisk to call the planner's attention to the option of creating a new order or rescheduling the old one. Should he reschedule? In this case, obviously not because the amount below Safety Stock is trivial and it is carried for just this reason.

PC 17534	OQ = 35	SS = 17	LT = 5

		W1	W2	W3	W4	W5	W6	W7
REQ'T		12	4	14	1	0	21	4
ON HAND	33	21	17	38	37	37	16	47
ON ORDER				35				35
PLANNED ORDER		**						

Figure 4

A difficult question was whether or not to let the system reschedule orders "automatically", responding to changing end product master schedules, excess scrap, record error corrections, unplanned withdrawals and the like. There was general agreement that rescheduling orders *out* in time automatic... would not cause any great difficulty. Rescheduling orders *in* earlier could be harmful, particularly when, as in Figure 4, it caused a reschedule that wasn't really necessary thus aggravating the "credibility" problem.

One of the important considerations in rescheduling is the ability of the environment to respond. A computerized daily dispatch list would react to automatic reschedules even if they were trivial but few shops can "turn on a dime". Automatic rescheduling could result in the purchasing department being flooded with computer generated order revisions that neither they nor the vendors could respond to. A real dilemma exists here and no company represented had sufficient experience with automatic rescheduling to resolve it. General agreement was reached among the more experienced users of requirements planning that a good rule might be: "Planned orders can be rescheduled automatically by the system; actual orders can be rescheduled only by the planner".

There was general agreement, however, that changing the *timing* of an order is much more desirable than changing the *quantity*. It was also recognized that the rescheduling load would be spread out by a weekly regeneration planning system since reschedules approved during one week would not trigger other reschedules at lower component levels until the following week. This would, of course, also delay reaction time.

K. *Net Change Versus Regeneration*

The discussion of net change versus regeneration brought out the following general conclusions:

1. Batch net change generally requires less computer operating time and produces less paperwork than regeneration.
2. Net change can be more responsive to changing requirements through daily processing.
3. Net change requires a great deal more discipline and maintenance of records.

The first two points are fairly evident; the third is perhaps not so obvious. Consider, for example, how a net change system would react for an item whose lead time was six weeks but is now reduced to four weeks. Subsequently, because of master schedule changes, an order or requirement at a high level is removed from the system. The computer will explode the change down through the component levels, offsetting the revised four weeks to indicate the effect on this item. Previously planned orders in the system based on the original six weeks lead time would be missed and remain unchanged. To be used effectively, all planned orders in a net change system must be realigned when lead times are changed.

The same problem arises when an engineering change alters the product structure record. If existing requirements based on the old product structure record have not been corrected and a net change run is made, the system will not be ordering the right material. Net change also requires tight mainenance routines to be sure that small over and underruns, record adjustments, etc., are balanced out correctly at all levels. A regeneration system recreates all requirements periodically and tends to be self-purging.

Net change seems to be the more demanding, yet more precise explosion technique, capable of producing more specific and useful output. The more experienced companies at this workshop used a net change system and felt strongly that net change was the only way to go, regenerating a new plan only at long intervals. Others felt that they would prefer to regenerate more often than they had been in order to purge the system and remove annoying errors.

L. *Allocation*

Although there seemed to be many interpretations of "allocation" as used in requirements planning, it was agreed that the best definition of an allocated order is one that has been released for picking by the stockroom but components have not yet been withdrawn from the stockroom. A synonym is "uncashed requisition". Data Control Systems reduces requirements by the quantity on an order released to the stockroom and then puts this quantity into their allocation record. When the components are pulled from the stockroom, both allocation and on-hand are relieved. If any parts shortages exist, backorders are created for each individual component and these continue to show as allocations. Black & Decker uses a somewhat different approach. When the system places a planned order in the current time period, indicating it should now be released, its component parts are automatically allocated at the next lower level. They are relieved from allocation and from on-hand when actually issued from stores.

The advantage of having an allocation record lies in the ability to show separately the quantity of parts on hand in the stockroom and the portion of these committed to orders in the stockroom calling for these parts in specific time periods. Set up as described here, there was general agreement that allocation was a most useful tool. The more common approach of showing all allocations without time-period identification buries much useful information which might influence rescheduling, expediting and altering assembly schedules.

M. *Pegged Requirements*

A requirement at one component level that can be traced to the next higher level component that caused it is called "pegged". A Level 2 component requirement, for example, would be pegged to show the Level 1 item that actually generated it. Black & Decker pegs requirements to an order number rather than a part number. General Railway Signal Company, using the IBM PICS packages, has chained their open order files to the item master to permit them to do the same thing. Data Control Systems and Dictaphone show only the identity of the higher level item that created the requirement; during regeneration as Level 1 item orders are exploded into Level 2 requirements, the identity of the Level 1 items is noted in the Level 2 record to generate a "one-level, live where-used file". Twin Disc actually separates customer orders from forecasts and explodes each down separately to show at any level the requirements caused by actual orders and those initiated by forecasts.

There was general agreement that pegging is a valuable addition to requirements planning. It is quite complex with a net change system but quite simple with regeneration where it is only necessary to post the identity of the higher level item causing the requirement. Identifying a requirement with its source provides invaluable information for rescheduling, balancing work input, safety stock determination and other decisions vital to successful use of requirements planning.

N. The IBM PICS Package

Mentioned earlier in this report, IBM's software programs, called the Production Information and Control System, include a number of inventory management programs. They are called "Bill of Material Processor", "Inventory Control" and "Requirements Planning". These packages are now released for use on System 360 / Model 30 and larger computers. They have similar programs available for Model 20 and 25 machines. Three of the initial users of the PICS program were included in the workshop, and, since many other workshop participants intended to use the PICS programs, this was a topic of great interest. The following points were brought out:

1. In general, the PICS packages are very useful, being provided with many options from which a workable program can be assembled. New Britain Machine and Markem Machine used the programs as provided with very little revision. At the other extreme, General Railway Signal modified them extensively, adding pegged requirements, lot-sizing variations and other features.
2. Figure 5 shows a typical printout from the PICS program which will be seen to lack data on available balances by time period. Every user of the PICS program felt that the standard printout showing only net requirements was satisfactory for ordering, but not satisfactory for rescheduling decisions. To handle such decisions, planners need to know how many parts are available to meet requirements in each time period. Manual calculations would be required to subtract the Allocated and the Safety Stock quantities (in the heading space) from the On Hand balance to figure the starting period's Available balance. Planners would then have to subtract gross requirements in each time period, adding in the open orders in proper time periods to get Available quantities in each period. Since this information is needed frequently it was felt desirable to have the computer calculate the projected available balance and print it as shown in Figure 6. The program steps for doing this, shown in Appendix 2, were

ON HAND 50 SS = 5

ALLOC. 20

GROSS REQ'T	35	50	100	5	10
OPEN ORD.		100			
NET REQ'T			60	5	10
OFF SET					

Figure 5

ON HAND 50 SS = 5

ALLOC. 20

GROSS REQ'T	35	50	100	5	10
OPEN ORD.		100			
NET REQ'T			60	5	10
OFFSET					
PROJECTED AVAILABLE BALANCE	-10	+40	-60	-65	-75

Figure 6

provided by Bruno Jobin, Manager of Programming, Markem Corporation, Keene, New Hampshire.

3. The PICS program allows for regeneration or net change (requirements alteration). There seemed to be no serious problems with either approach; however, care must be exercised when using net change since there is no provision in the requirements alteration program to insure that component changes resulting from an engineering change will be handled properly. The problem arises because there are no program steps to remove old requirements and reinstate new ones automatically when an engineering change affects the bill of material. An engineering change affecting the product structure record would, of course, be handled correctly with regeneration.
4. Safety stock is not calculated in the PICS program, but there are program exits so that sub-routines developed by the user can be tied in properly.
5. The lot-sizing techniques provided in the PICS program raise some problems as discussed in Section H above. There are, however, user exits by which the POQ or least total cost techniques without "look-ahead / look-back" could be programmed and tied in fairly easily.
6. The PICS program facing a situation like that shown in Figure 4 would print out an exception report indicating the need for rescheduling the order. However, it should be clearly understood that it would develop a new planned order and proceed from there to the next level down assuming that the open order *had not been rescheduled*.
7. "Conversational planning" which permits stepping down through the plan one level at a time, had not been used by any of the companies and they didn't see it as a particularly useful tool, even for education.

In general, the users of the PICS package were quite pleased with it. They felt that it had helped them to develop and implement their requirements planning program in considerably less time than would have been required if they had to write all programs themselves. New Britain Machine installed the Bill of Material Processor, the Inventory Control package and the Requirements Planning module and completed all of this in less than seven months. This is a very commendable achievement; many companies have spent a year or even more just getting the Bill of Material Processor program operating. In view of the large potential savings, any means like PICS to reduce the systems design and programming time is worth very serious consideration. Additional dividends result because use of the package prevents gross errors, omissions, or useless sophistication likely in "home-grown" programs designed by inexperienced people.

V. Conclusions

This Special Report does not cover all aspects of requirements planning. Many topics, such as detailed exception reports, and methods of structuring bills of material were not covered in the workshop because they were of relatively little interest to this particular group. Other topics, such as many potential areas of saving, the use of "phantom bills of material" to handle sub-assemblies produced but not stocked, and techniques for allocating common components against assembly requirements were also omitted from this report because time did not permit them to be covered during the workshop in sufficient depth. This does not mean that such subjects are unimportant when developing a requirements planning system. This report is intended only to distill and make available to others the practical experiences exchanged at this workshop, together with explanatory material necessary for an adequate understanding by practitioners without previous experience in using requirements planning.

The general conclusions that can be drawn from this workshop are:

1. Requirements planning is a powerful tool useful in a company making products that have components with dependent demand.
2. The tool has proven its power and usefulness by successful application in a number of companies.
3. The number of companies using the tool is a very small fraction of those who could benefit from such use.
4. There is still much to be learned about some of the finer points of requirements planning.
5. The literature published in this field contains little on the subject, almost nothing on practical applications.
6. Because previous inventory systems were not capable of keeping priorities up to date most companies relied very heavily on their "informal" systems – the shortage and hot lists. Requirements planning has the potential to provide more realistic, useful priority information as part of the "formal" system. Most companies experience difficulty in realizing this potential – primarily because of a tendency to overstate requirements in the master schedule.

The attendees at the workshop felt that the two and a half days were not long enough to cover the important topics in the depth they would have liked. All recognized there is much more involved in learning to use requirements planning effectively than is apparent at first exposure. This type of workshop, obviously, will have to be repeated.

VI. Recommendations

While a great deal of research and development effort has been expended in some areas of production and inventory control, little has been related to requirements planning. Areas requiring further research are:

1. Development of requirements planning simulator to demonstrate the obvious power of the technique and provide a teaching medium.
2. Testing in a real-world environment the various approaches to lot-sizing in a multi-level product structure to realize the benefits and minimize the problems of dynamic lot-sizing.
3. Development of methods for determining optimum safety stocks for lower level components in a requirements plan and the definition of service levels insured by these safety stocks.
4. Identification and definition of the important factors to be considered in structuring bills of material to acheive maximum benefits.
5. Development of engineering change control procedures to minimize potential losses.
6. Study of best methods of linking requirements planning, capacity planning, scheduling and costing systems to use common data sources and provide needed checks and balances in an operating environment.

VII. Bibliography

I. *APICS HANDBOOK*, McGraw-Hill, New York, NY 1970 Chapter 17, "Requirements Planning Systems".

II. Everdell, Romeyn, "Time Phasing", *Modern Materials Handling*, November, 1968.

III. Wight, O. W., "To Order Point or Not To Order Point", *Journal of Production and Inventory Management*, November, 1968.

IV. Garwood, Dave, "Stop, Before You Use The Bill Processor", *Journal of Production and Inventory Management*, Second Quarter, 1970.

12/15/69 W 316 INVENTORY STATUS CODE A FOR 80057457-05 (PART NUMBER OR RAW MATERIAL CODE) BLACK AND DECKER PRINTOUT — EXHIBIT I-A — INDIVIDUAL PART (TITLE OF INQUIRY) REQUESTED BY ORDER (NAME) 813-91 (DEPT NO)

4

LINE	PART NUMBER OR RAW MATERIAL CODE	DESCRIPTION	UNIT OF MEASURE								DATE OF LAST	DATE LAST		
1	80057457-05	CASE FLD & SW	50	A							474	513		8

	LEAD TIME			WEEK FACTOR	SAFETY STOCK					USAGE LAST YEAR		USAGE YEAR TO DATE				ON HAND	ALLOCATED		
K		5		03				1	1	62500		12397				273			8

	PAST DUE	CURRENT WEEK	WEEK 515	WEEK 516	WEEK 517	WEEK 518	WEEK 519	WEEK 520	WEEK 521	WEEK 522	WEEK 523	WEEK 524	WEEK 525	WEEK 526
[illegible]									6700			600		1957
[illegible]							3409							
[illegible]							10850							
[illegible]		273	273	273	273	273	7398	7398	698	698	698	98	98	1859-
[illegible]									1915		5016	2016	412	16763

	WEEK 527	WEEK 528	WEEK 529	WEEK 530	WEEK 531	WEEK 532	WEEK 533	WEEK 534	WEEK 535	WEEK 536	WEEK 537	WEEK 538	WEEK 539	WEEK 540
[illegible]		4870	1957	400	16275						13600			
[illegible]														
[illegible]														
[illegible]	1859-	6729-	8686-	9086-	25361-	25361-	25361-	25361-	25361-	25361-	38961-	38561-	38961-	38961-
[illegible]						14008							12818	

	WEEK 541	WEEK 542	WEEK 543	WEEK 544	WEEK 545	WEEK 546	WEEK 547	WEEK 548	WEEK 549	WEEK 550	WEEK 551	WEEK 552	WEEK 553	WEEK 554
[illegible]				12445							400			8265
[illegible]														
[illegible]														
[illegible]	38961-	38961-	38961-	51406-	51406-	51406-	51406-	51406-	51406-	51406-	51806-	51806-	51806-	60071-
[illegible]						412			8513					

	WEEK 555	WEEK 556	WEEK 557	WEEK 558	WEEK 559	WEEK 560	WEEK 561	WEEK 562	WEEK 563	WEEK 564	WEEK 565			TOTALS
[illegible]														67469
[illegible]														3409
[illegible]														10850
[illegible]	60071-	60071-	60071-	60071-	60071-	60071-	60071-	60071-	60071-	60071-	60071-			60071-
[illegible]														61873

ORDERS OUT OF PHASE

STATUS

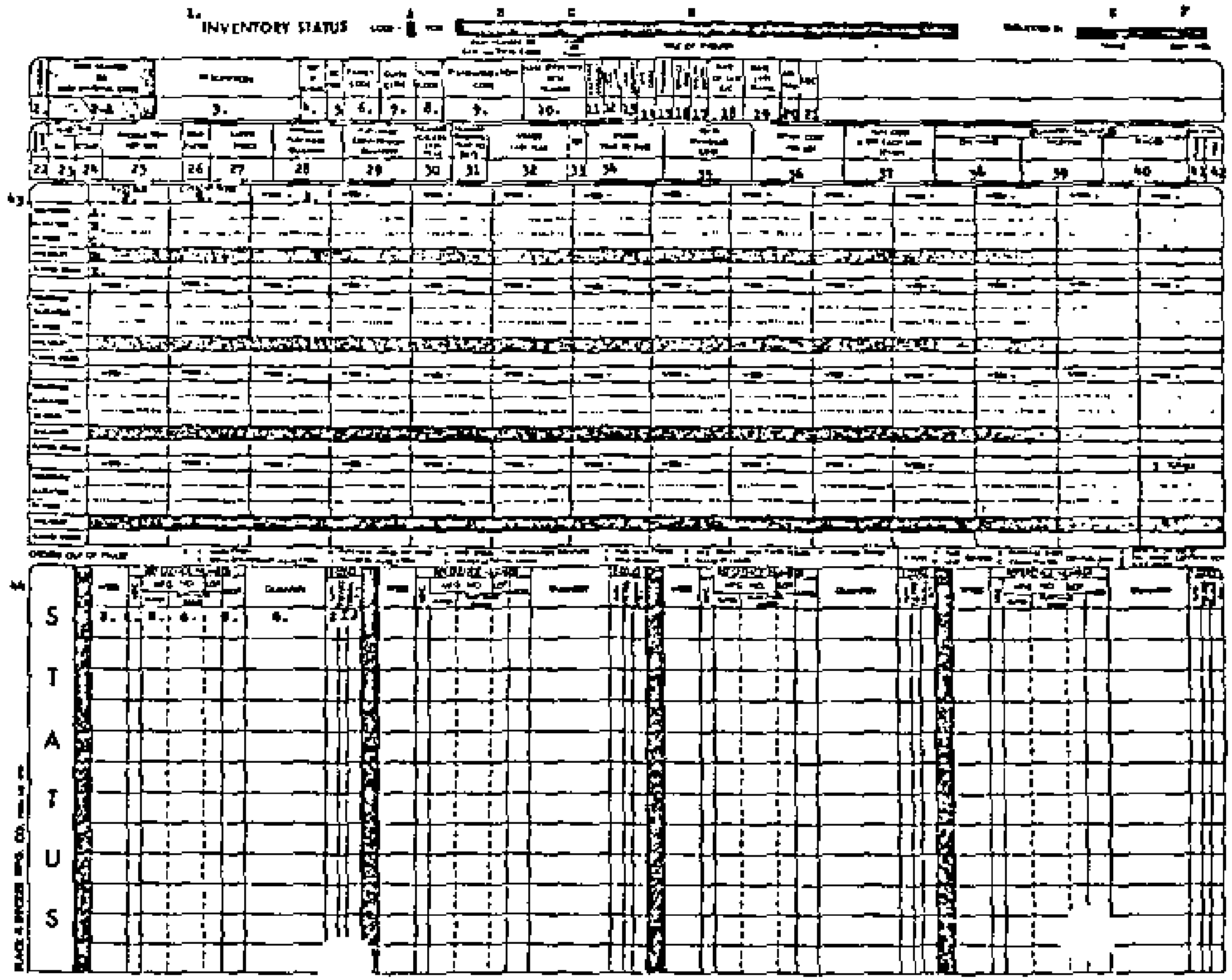
CODE	WEEK	MFG NO / ROUTING	QUANTITY		CODE	WEEK	MFG NO / ROUTING	QUANTITY		CODE	WEEK	MFG NO / ROUTING	QUANTITY		CODE	WEEK	MFG NO / ROUTING	QUANTITY	
		REQUIREMENTS	START-HERE—		R	521	8003442158	6700	U	R	524	8006456710	600	U	R	526	8003442102	1957	U
R	528	8003442102	4870	U	R	529	8003442102	1957	U	R	530	8003606248	400	U	R	531	8003442104	16275	U
R	537	8003442106	13600	U	R	544	8003442108	12445		R	551	8003606250	400		R	554	8003442110	8265	
		ALLOCATIONS	START-HERE—		A	519	8506369800	3141	U	A	519	8003442158	268	U					
		ORDERS	START-HERE—		S	519	8003442158	10850	UC			PLANNED ORDERS	START-HERE—		U	521	8003442102	1915	U
U	523	8003442102	5016	U	U	524	8003442102	2016	U	U	525	8003606248	412	U	U	526	8003442102	16763	U
U	532	8003442106	14008	U	U	539	8003442108	12818		U	546	8003606250	412		U	549	8003442110	8513	

BLACK & DECKER MFG. CO.

1. A. Inquiry origination - Program or individual request
   B. Part requested - Always parent part if component is subassembly
   C. If inquiry was by Class Code or Family Group, number prints here.
   D. Was inquiry for individual part, group of parts or full Bill of Material.
   E. Name of person or program requesting status print out.
   F. If personal request, employee number and department, if program request - program number.
2. Manufactured, Purchased, Raw Material or Supply Item Designator Code
   A. Code number for this individual piece part or material.
3. Description of 2-A.
4. Pieces - Pounds - etc.
5. Proportional Distribution Code
6. Combination Plus or Parts - Groups parts together.
7. Types of parts, bearings, switches.
8. Responsible buyer
9. Engineering specs, drawing size, etc.
10. Last Engineering Change affecting this part.
11. Indicates if this is a saleable end item.
12. Grouping Code for top level units. (Not presently in use)
13. Indicates a functional group of components into packaging.
14. Product Line Code - Consumer goods - Professional, etc.
15. Assembly Dept. - Sub assembly for explode alternates
16. Indicates service only parts
17. Does this part require a special long lead [illegible] letter.
18. Date of last Inventory Cycle Count
19. Date of last Inventory transactions
20. Is there an Engineering Change pending against this part.
21. Responsible plant of manufacturing.
22. Ordering Logic Code. EOQ. Lot/Lot. Search Fixed. [illegible]
23. Applies to purchased sub assemblies only - Time required by vendor for fabrication.
24. Time required to make or buy this specific part.
25. Quantity of parts to be purchased or manufactured.
26. % of material extra to cover factory loss.
27. Amount of on hand inventory to be held. First entered from on hand to calculate availability.
28. Minimum quantity at which purchasing can hold standard cost.
29. Possible multiples in which Purchasing must buy (Ex. 55 gal. - drums)
30. Number of orders purchased or manufactured last fiscal year.
31. Number of orders purchased or manufactured this Fiscal Year to date.
32. Number of items used last Fiscal Year.
33. If Usage Last Year is estimated, asterisk prints here.
34. Number of items used this Fiscal Year to date.
35. Total material, labor and overhead costs per piece.
36. Costs to set up all equipment to manufacture one lot size.
37. Total Cost each less set-up cost each.
38. Current on hand balance.

   B. Demand which supports an on order condition at parent plant.
   C. Orders placed on Purchasing or the Factory.
   D. Material available at any given point.
   E. To be ordered. Decide in week which order must be placed. Mechanically adjusted.
   F. Material profile with dates earlier than current week.
   G. Material profile for past due, and current week.
   H. First week of profile. From here projects out 52 weeks.
   I. 52 week totals of demand and order profile.
44. Pegged requirement status, showing the reference number and lot generating demand and/or subsequent orders.

   A. Indicates if blank or [illegible] exploded demand. Also indicates status of open on orders, as sold, first operation complete, etc.
   B. Required production week.
   C. Plant location of demand and/or order.
   D. If purchased part, buyer code number.
   E. If purchased part, purchase order number.
   (D. & E. if manufactured, unit number and lot)
   F. Model number of end item where applicable.
   G. Quantity of demand and/or order.
   H. Identifies unit or piece part demand.
   I. Identifies if order has schedule sheet issued, or if components have been coordinated.
   J. Status of Engineering Change Controlling Demand.
39. Material in receiving but not inspected for Storeroom acceptance.
40. Parts physically staged for given production lot. (Not in use)
41. Plant in which the stated on hand inventory is located.
42. Storeroom general location.
43. Weekly Requirements and Order Profile.
   A. Demand which supports a planned order at parent plant.



EXHIBIT

MATERIAL REQUIREMENTS PLAN

DATA-CONTROL SYSTEMS, INC.

PURCHASING COPY

AS OF 04/04/69 CURRENT WEEK NO. 66 REPORT DATE 04/08/69 TR NO. 776 PAGE NO. 15

AD 011430	RIGHT RAIL	EA	3. +	0. =	3.	6	1	8	8	/ /	15.

MESSAGES [illegible]

	PAST DUE	CURRENT	WK. ENDING 04/11	WK. ENDING 04/18	WK. ENDING 04/25	WK. ENDING 05/02	WK. ENDING 05/09	WK. ENDING 05/16	WK. ENDING 05/23	WK. ENDING 05/30	WK. ENDING 06/06	WK. ENDING 06/13	WK. ENDING 06/20	WK. ENDING 06/27	WK. ENDING 07/04	WK. ENDING 07/11	WK. ENDING 07/18	TOTALS
FORECAST	0.	0.	5.	0.	10.	0.	0.	10.	0.	0.	0.	0.	5.	5.	0.	0.	0.	35.
ALLOCATION	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ON HAND	3.	21.	16.	16.	6.	6.	6.	[illegible]	16.	16.	16.	16.	11.	6.	6.	6.	6.	6.
ON ORDER	3.	15.	0.	0.	0.	0.	0.	20.	0.	0.	0.	0.	0.	0.	0.	0.	0.	38.
PLANNED ORDER	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

ITEMS IN FORECAST: 231 327
ITEMS IN ALLOCATION:

AD 011431	CHASSIS	EA	20. +	0. =	20.	3	1	8	3	/ /	105.

MESSAGES [illegible]

	PAST DUE	CURRENT	WK. ENDING 04/11	WK. ENDING 04/18	WK. ENDING 04/25	WK. ENDING 05/02	WK. ENDING 05/09	WK. ENDING 05/16	WK. ENDING 05/23	WK. ENDING 05/30	WK. ENDING 06/06	WK. ENDING 06/13	WK. ENDING 06/20	WK. ENDING 06/27	WK. ENDING 07/04	WK. ENDING 07/11	WK. ENDING 07/18	TOTALS
FORECAST	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	10.	10.	0.	0.	0.	0.	6.	26.
ALLOCATION	0.	5.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	6.
ON HAND	20.	15.	14.	14.	14.	14.	14.	14.	14.	14.	4.	-6.	-6.	-6.	-6.	-6.	-12.	-12.
ON ORDER	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
PLANNED ORDER	0.	0.	0.	15.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

ITEMS IN FORECAST 282 303 315
ITEMS IN ALLOCATION:315 282

AD 011433	VCO BOARD	EA	33. +	0. =	33.	17	1	5	5	/ /	36.

MESSAGES BB 05/16

	PAST DUE	CURRENT	WK. ENDING 04/11	WK. ENDING 04/18	WK. ENDING 04/25	WK. ENDING 05/02	WK. ENDING 05/09	WK. ENDING 05/16	WK. ENDING 05/23	WK. ENDING 05/30	WK. ENDING 06/06	WK. ENDING 06/13	WK. ENDING 06/20	WK. ENDING 06/27	WK. ENDING 07/04	WK. ENDING 07/11	WK. ENDING 07/18	TOTALS
FORECAST	0.	0.	12.	0.	14.	1.	0.	21.	4.	0.	0.	0.	15.	5.	0.	6.	0.	78.
ALLOCATION	0.	0.	0.	4.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.
ON HAND	33.	33.	21.	17.	38.	37.	37.	16.	47.	47.	47.	47.	32.	27.	27.	21.	21.	21.
ON ORDER	0.	0.	0.	0.	35.	0.	0.	0.	35.	0.	0.	0.	0.	0.	0.	0.	0.	70.
PLANNED ORDER	0.	0.	******	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

ITEMS IN FORECAST: 004 009 021 022 231 327
ITEMS IN ALLOCATION 009

AD 011451	FRONT PANEL	EA	0. +	55. =	55.	16	1	8	2	/ /	102.

MESSAGES GG

	PAST DUE	CURRENT	WK. ENDING 04/11	WK. ENDING 04/18	WK. ENDING 04/25	WK. ENDING 05/02	WK. ENDING 05/09	WK. ENDING 05/16	WK. ENDING 05/23	WK. ENDING 05/30	WK. ENDING 06/06	WK. ENDING 06/13	WK. ENDING 06/20	WK. ENDING 06/27	WK. ENDING 07/04	WK. ENDING 07/11	WK. ENDING 07/18	TOTALS
FORECAST	0.	0.	0.	0.	15.	0.	0.	0.	5.	0.	0.	0.	0.	0.	0.	0.	0.	15.
ALLOCATION	3.	6.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	11.
ON HAND	55.	46.	44.	44.	29.	29.	29.	25.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.
ON ORDER	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
PLANNED ORDER	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]

ITEMS IN FORECAST: 246
ITEMS IN ALLOCATION 246

AA = OPEN ORDER IN THE PAST DUE PERIOD.
BB = PLANNED ORDER IN ADDITION TO AN EXISTING ORDER IN A FUTURE PERIOD.
CC = MATERIAL ON ORDER THAT IS NOT REQUIRED IN ANY PERIOD.
DD = MATERIAL ON ORDER THAT EXCEEDS 16 WEEK REQUIREMENTS (MATERIAL ADDED TO 16TH PERIOD.)
EE = LEAD TIME IS ZERO OR SAFETY STOCK IS ZERO.
FF = PLANNED ORDER RELEASE.
GG = ON HAND IS BELOW SAFETY HOWEVER MATERIAL IN M.W.R.

Dictaphone

MATERIALS PLANNING WORKSHEET

DATE 12/05/88 WEEK 40 — PAGE [illegible]

PART NUMBER / DESCRIPTION									
1196-000 ALL STEEL	CHS PCS	13470	0	100000	380400	2220	0	0164 7000000100	1490
09	[illegible]	178570-000	121944-000						

1985	1019	866	100000	1243	2974-			
88 / 399-	1960 / 1961-	88 / 1990-	1510 / 1567-	98 / 2385-	1360 / 6194-	137 / 3291-		
1178 / 6417-	49 / 6510-							
6505	0	0	6510-	10000	0			

PART NUMBER / DESCRIPTION									
1205-177 RESISTOR	CABC PCS	0	0	1000060	006	0	0	5688200000000100	0
01	[illegible]								

1998	90	1902			
0	0	0	90	1908	0

CENTRAL RAILWAY SIGNAL COMPANY

EXHIBIT IV

REQUIREMENTS PLANNING STATUS

INVENTORY CONTROL ACTION REPORT

DEPT 03 RESP 1

10/ 3/69 40

Item	A517A 1A
Description	CRYSTAL
	1/58
	7 12 66 0
	2/58 EEA 6 0
	802 21 37 159 064607 0
	386
Total	385.00
	1952100
	75.49
	297 36/69
	386

	39/0	OCT 40/9	41/9	42/9	43/9	NOV 44/9	45/9	46/9	47/9	DEC 48/9	49/9	50/9	51/9	52/9	JAN 1/0	2/0
Gross req / Effective bus inf													396	216		
Net req													10	216		
Planned bus inf													10	216		
PAB	386	386	386	386	386	386	386	386	356	356	386	386	10-	226-	226-	226-

	3/0	FEB 4/0	5/0	6/0	7/0	MAR 8/0	9/0	10/0	11/0	12/0	APR 13/0	14/0	15/0	16/0	MAY 17/0	18/0
Gross req / Effective bus inf																
Net req																
Planned bus inf																
PAB	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-

	19/0	20/0	JUN 21/0	22/0	23/0	24/0	25/0	JUL 26/0	27/0	28/0	29/0	AUG 30/0	31/0	BEYOND	TOTAL	999
Gross req / Effective bus inf															612	
Net req															226	
Planned bus inf															226	
PAB	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-	226-

TRANSACTION STATUS CODES

	Order number	Drawing no. of next level bus inf	Quantity
E	A519040970000002 65		10
E	A519040970000002 64		216
	A519040970000002 63		10
	B519040970000001 464	59473 80 1	216

	Order number	Drawing no. of next level bus inf	Quantity
00	PLANNED O/W REQUIRES APPROVAL		
00	PLANNED O/W REQUIRES APPROVAL		
	A519040970000002 64		216
	B519040970000001 465	59473 79 1	396

PART NO. 0282301 POLICY CODE G DESCRIPTION – TURNOVER GEAR BKT

ITEM TYPE 2 INV. CLASS B SOURCE M UNIT OF MEASURE EACH ORDER QUANTITY 80 SAFETY STOCK LEAD TIME 8

UNIT COST [redacted] INVENTORY BALANCE 41 MIN. MAX. MULT. ALLOC. 1ST AVE. .0

	609	614	619	624	629	634	639	644	649
GROSS	10	10	9			30			7
OPEN ORD						80 *			
NET									
OFFSET								80 *	
BALANCE	31	21	12	12	12	62	62	62	55

	654	659	664	669	674	679	684	689	694
GROSS	10	20				17	22		
OPEN ORD									
NET							14		
OFFSET									
BALANCE	45	25	25	25	25	8	66	66	66

	699	704	709	714	719	724	729	734	739
GROSS			35		2				
OPEN ORD									
NET			35		2				
OFFSET									
BALANCE	66	66	31	31	29	29	29	29	29

PART NO. 0282315 POLICY CODE G DESCRIPTION – BLOCK

ITEM TYPE 2 INV. CLASS D SOURCE M UNIT OF MEASURE EACH ORDER QUANTITY SAFETY STOCK LEAD TIME 8

UNIT COST [redacted] INVENTORY BALANCE 7 MIN. MAX. MULT. ALLOC. 1ST AVE. .0

	609	614	619	624	629	634	639	644	649
GROSS	3		2		2			2	
OPEN ORD								10 *	
BALANCE	4	4	2	2				8	8

	654	659	664	669	674	679	684	689	694
GROSS		2			2			2	
OPEN ORD									
BALANCE	8	6	6	6	4	4	4	2	2

	699	704	709	714	719	724	729	734	739
GROSS									
OPEN ORD									
BALANCE	2	2	2	2	2	2	2	2	2

PART NO. 0282317 POLICY CODE G DESCRIPTION – BRACKET

ITEM TYPE 2 INV. CLASS D SOURCE M UNIT OF MEASURE EACH ORDER QUANTITY SAFETY STOCK LEAD TIME 6

UNIT COST [redacted] INVENTORY BALANCE 10 MIN. MAX. MULT. ALLOC. 1ST AVE. .0

	609	614	619	624	629	634	639	644	649
GROSS	4		3		3			3	
OPEN ORD								15 *	
BALANCE	6	6	3	3				12	12

	654	659	664	669	674	679	684	689	694
GROSS		3			3			3	
OPEN ORD									
BALANCE	12	9	9	9	6	6	6	3	3

	699	704	709	714	719	724	729	734	739
GROSS									
OPEN ORD									
BALANCE	3	3	3	3	3	3	3	3	3

EXHIBIT VI

NEW BRITAIN MACHINE COMPANY
HAND TOOLS DIVISION - PLANNING SHEET FOR WEEK NO. 6 BEGINNING 02/02/70

6

ON HAND = 9,113 PART NO.= 11-422633 DESC=SOCKET 1/2DR 13/16 X DP 12PT BD-IT CODE-TOOL TYPE 03-82200-118
CUS-ALLOC TYPE ITEM 2 CRD CODE F LOT SIZE FIRST AVR SORT KEY 111-422633
MFG ALLOC 7,147 VAL CLASS A FORECAST 4 LEVEL CODE. 3 AVR USAGE 2,435 LEAD TIME 15
SAF STOCK 5 SS CODE 8 SS FACTOR .10 YTD CUST DEMAND

	1/05/70	1/12/70	1/19/70	1/26/70	2/02/70	2/09/70	2/16/70	2/23/70	3/02/70
GROSS REQ				112	70		2,724	6,165	2,200
OPEN ORD	11,000								
NET REQ									310
PLAN RECP									4,900
PLAN ORD						4,900			12,400

	3/09/70	3/16/70	3/23/70	3/30/70	4/06/70	4/13/70	4/20/70	4/27/70	5/04/70
GROSS REQ	3,570	1,009	6,338	3,000	3,000	3,180	3,000	5,988	5,890
OPEN ORD									
NET REQ	3,570	1,009	6,338	3,000	3,000	3,180	3,000	5,988	5,890
PLAN RECP			12,400			12,100			12,100
PLAN ORD			12,100			12,100			10,800

	5/11/70	5/18/70	5/25/70	6/01/70	6/08/70	6/15/70	6/22/70	6/29/70	7/06/70
GROSS REQ	3,000	3,120	4,640	3,225	3,000	3,000	3,975	3,000	3,220
OPEN ORD									
NET REQ	3,000	3,120	4,640	3,225	3,000	3,000	3,975	3,000	3,220
PLAN RECP			10,800			10,000			10,400
PLAN ORD			10,000			10,400			7,900

	7/13/70	7/20/70	7/27/70	8/03/70	8/10/70	8/17/70	8/24/70	8/31/70	9/07/70
GROSS REQ	4,000	3,215	3,000	3,027				1,890	
OPEN ORD									
NET REQ	4,000	3,215	3,000	3,027				1,890	
PLAN RECP			7,900						
PLAN ORD									

DODGE MANUFACTURING CORPORATION — DIVISION OF RELIANCE ELECTRIC COMPANY

EXHIBIT VII

MATERIAL REQUIREMENTS PLAN—PARTS AS OF 07/13/70 WEEK DAY PAGE 1

011643 100A SCR REGULATOR MODULE ASSY M30 39 .000 / / H A0 120 COMPONENT PART

908 35 998 6 662 26 - 120 - 94-

EXCEPTIONS

	PAST DUE	CURRENT	WEEK OF 7/20	WEEK OF 8/10	WEEK OF 8/17	WEEK OF 8/24	WEEK OF 8/31	WEEK OF 9/07	WEEK OF 9/14	WEEK OF 9/21	WEEK OF 9/28	WEEK OF 10/05	WEEK OF 10/12	WEEK OF 10/19	WEEK OF 10/26	WEEK OF 11/02	WEEK OF 11/09	WEEK OF 11/16	WEEK OF 11/23
GROSS REQUIREMENTS				20	42	4			66				42	20				42	
NET AVAILABLE	46	43	43	23	18-	18-	19-	20-	83-	83-	83-	84-	126-	146-	147-	151-	148-	210-	211-
ON ORDER	140																		
PLANNED ORDERS					60				60				60					60	
START PLANNED ORDERS			60				60				60					60			

011125 255F POWER RELAY MODULE M30 19 .000 / / 1 8 COMPONENT PART

53 10 85 49 19 - 6 - 4

EXCEPTIONS

	PAST DUE	CURRENT	WEEK OF 7/20	WEEK OF 8/10	WEEK OF 8/17	WEEK OF 8/24	WEEK OF 8/31	WEEK OF 9/07	WEEK OF 9/14	WEEK OF 9/21	WEEK OF 9/28	WEEK OF 10/05	WEEK OF 10/12	WEEK OF 10/19	WEEK OF 10/26	WEEK OF 11/02	WEEK OF 11/09	WEEK OF 11/16	WEEK OF 11/23
GROSS REQUIREMENTS						4				5				4				4	
NET AVAILABLE	4	4	4	4	3	1-	1-	1-	1-	6-	6-	6-	6-	10-	11-	11-	11-	15-	15-
ON ORDER																			
PLANNED ORDERS						8								8					
START PLANNED ORDERS				8								8							8

018233 51 DIODE 4CA 200 PIV 174-28 3110 030 23 A .000 / / K - 240 COMPONENT PART

018233NA 2354 2 2103 1685 141 - - 141

EXCEPTIONS 04 07

	PAST DUE	CURRENT	WEEK OF 7/20	WEEK OF 8/10	WEEK OF 8/17	WEEK OF 8/24	WEEK OF 8/31	WEEK OF 9/07	WEEK OF 9/14	WEEK OF 9/21	WEEK OF 9/28	WEEK OF 10/05	WEEK OF 10/12	WEEK OF 10/19	WEEK OF 10/26	WEEK OF 11/02	WEEK OF 11/09	WEEK OF 11/16	WEEK OF 11/23
GROSS REQUIREMENTS		2	122	2		2	122	2	20	2	122	122	20	2	2	130	20	2	6
NET AVAILABLE	341	339	217	465	463	461	339	337	317	315	193	71	51	49	47	83-	103-	105-	111-
ON ORDER	160			250															
PLANNED ORDERS												240				240			
START PLANNED ORDERS		240				240					240							240	

018240 PRPN TRIGGER DIODE U30 50 B .000 / / T 360 COMPONENT PART

018240NA 6445 300 4045 25 4137 436 - 30 - 360

EXCEPTIONS 08 06 06 06 19

	PAST DUE	CURRENT	WEEK OF 7/20	WEEK OF 8/10	WEEK OF 8/17	WEEK OF 8/24	WEEK OF 8/31	WEEK OF 9/07	WEEK OF 9/14	WEEK OF 9/21	WEEK OF 9/28	WEEK OF 10/05	WEEK OF 10/12	WEEK OF 10/19	WEEK OF 10/26	WEEK OF 11/02	WEEK OF 11/09	WEEK OF 11/16	WEEK OF 11/23
GROSS REQUIREMENTS		6	61	285	5	11	142	86	216	68	96	81	300	6	86	142	17	233	85
NET AVAILABLE	386	380	279	6-	11-	22-	164-	750	534	466	370	289	11-	17-	103-	245-	260-	493-	570-
ON ORDER								1000											
PLANNED ORDERS													360					360	
START PLANNED ORDERS			360					360			360		360			360		360	

018252 SCR CELL 110 A C45 4CUV 028 70 A .000 / / N 26 30 COMPONENT PART

018252NA 333 159- 234 24 - 30 - 6-

EXCEPTIONS 08 01 14 19

	PAST DUE	CURRENT	WEEK OF 7/20	WEEK OF 8/10	WEEK OF 8/17	WEEK OF 8/24	WEEK OF 8/31	WEEK OF 9/07	WEEK OF 9/14	WEEK OF 9/21	WEEK OF 9/28	WEEK OF 10/05	WEEK OF 10/12	WEEK OF 10/19	WEEK OF 10/26	WEEK OF 11/02	WEEK OF 11/09	WEEK OF 11/16	WEEK OF 11/23
GROSS REQUIREMENTS								30				30							
NET AVAILABLE	6-	6-	6-	24	24	24	24	6-	6-	6-	6-	36-	36-	36-	36-	36-	36-	36-	36-
ON ORDER				30															
PLANNED ORDERS								26				26							
START PLANNED ORDERS				26				26								26			

FORM NO. 1 B

PLANNING STATUS REPORT

MFD 264 | FOB 1145 | M-DAY 926 | DATE C9/12/70 | PAGE 27

PART NO. I000030318120 **DESCRIPTION** INSERT, NEBULIZER — LOC 08 — TYPE 216430 — R — 1 — LT 10 — C.L.T. 40 — FOQ 4

ON HAND 762 — ALLOC 125 — BACK LOC 60974 — TOTAL USE 1 — 1

	PAST DUE 907	926	WEEKLY PLAN 931	936	941	946	951	956	961	966	971	976	MONTHLY PLAN 992	11	31	51	70	90	109	128	148	167	172
SALES PLAN	2	3	3	0	0	0	3	0	0	0	3	0	3	3	0	0	0	0	0	0	0	0	0
IRP PLAN	237	487	128	0	0	210	105	0	0	121	100	0	420	236	270	292	273	205	305	110	0	0	0
OTHER PLAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL PLAN	239	490	131	0	0	210	108	0	0	121	103	0	423	239	270	292	273	205	305	110	0	0	0
RELEASED ORDS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJ ON HAND	523	33	-98	-98	-98	-308	-416	-416	-416	-537	-640	-640	-1063	-1302	-1572	-1864	-2137	-2342	-2647	-2757	-2757	-2757	-2757
PLANNED ORDS	0	387	0	0	0	194	0	0	0	333	0	0	314	325	311	256	230	205	205	0	0	0	0

WHERE USED: I000030304750- 1 I000030313540- 1
ORDER NO: NO ORDERS-
ALLOCATIONS: K05953700- 260-907 K06716500- 125-946

PART NO. I000030318460 **DESCRIPTION** PIVOT-CHOPPER MOUNT — LOC 08 — TYPE 11430 — F — 1 — LT 20 — C.L.T. 20 — FOQ 10

ON HAND 328 — ON ORDER 215 — ALLOC 100 — TOTAL USE 151 — OTHER USE 24

	PAST DUE 907	926	WEEKLY PLAN 931	936	941	946	951	956	961	966	971	976	MONTHLY PLAN 992	11	31	51	70	90	109	128	148	167	172
SALES PLAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IRP PLAN	134	55	143	0	0	0	0	0	50	0	0	0	77	47	87	42	80	0	0	0	0	0	0
OTHER PLAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL PLAN	134	55	143	0	0	0	0	0	50	0	0	0	77	47	87	42	80	0	0	0	0	0	0
RELEASED ORDS	0	0	215	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJ ON HAND	194	139	211	211	211	211	211	211	161	161	161	161	84	37	-50	-92	-172	-172	-172	-172	-172	-172	-172
PLANNED ORDS	0	0	0	0	0	0	0	0	0	0	0	0	0	172	0	0	0	0	0	0	0	0	0

WHERE USED: I000030300080- 1
ORDER NO: K06430600- 215-931
ALLOCATIONS: K06413700- 100-918

PART NO. I000030318890 **DESCRIPTION** PLATE-ADJUSTING — LOC 08 — TYPE 311430 — R — 1 — LT 20 — C.L.T. 20 — FOQ 10

ON HAND 530 — ALLOC 100 — TOTAL USE 127

	PAST DUE 907	926	WEEKLY PLAN 931	936	941	946	951	956	961	966	971	976	MONTHLY PLAN 992	11	31	51	70	90	109	128	148	167	172
SALES PLAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IRP PLAN	134	55	143	0	0	0	0	0	50	0	0	0	77	47	87	42	80	0	0	0	0	0	0
OTHER PLAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL PLAN	134	55	143	0	0	0	0	0	50	0	0	0	77	47	87	42	80	0	0	0	0	0	0
RELEASED ORDS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJ ON HAND	396	341	198	198	198	198	198	198	148	148	148	148	71	24	-63	-105	-185	-185	-185	-185	-185	-185	-185
PLANNED ORDS	0	0	0	0	0	0	0	0	0	0	0	0	0	185	0	0	0	0	0	0	0	0	0

WHERE USED: I000030390080- 1
ORDER NO: NO ORDERS-
ALLOCATIONS: K06413700- 100-918

TWIN DISC, INCORPORATED — EXHIBIT IX — MATERIAL STATUS - PRODUCTION SCHEDULE

PART NUMBER	NAME	FORECAST QUANTITY	USED LAST YEAR	USED TO DATE	USED THIS PERIOD	YEAR TO DATE SCRAP	SAFETY STOCK	LEAD TIME	E.O.Q.	SM CONS	REQ. FREQ	SPECIAL INSTRUCTIONS	MODEL USED ON	LOWER LEVEL OR CRITICAL PART NUMBER: PART NUMBER	LOWER LEVEL OR CRITICAL PART NUMBER: QUANTITY	PRINT DATE
201392 X	SPACER	25	2250	387			90	3	500	15	4	C-DND.-	6F13	# 404	2352	09/12/69

UNREL W.O.	ALLOC NOT IN PROCESS	ACTION REQUIRED: TYPE	DUE	QUANTITY	AUTHORITY	SERVICE DELIVERY THIS YEAR	SERVICE DELIVERY LAST YEAR	MOVEMENT QUANTITY	MATERIAL COST	LABOR COST	
						35	45				3

	PAST DUE	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288
REQUIREMENTS	433	120	10	11	152	104	60	80	193	47	20	10	166	152	90	25	107	107
SCHED RECEIPTS	61																	
AVAILABLE	1553	971	961	950	798	694	634	554	361	314	289	264	98	54-	144-	169-	276-	383-
PLANNED ORDERS										500							500	

	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306
											10	25	107	107		20	99	187
REQUIREMENTS		20	99	187	2	25	54	43	40	30	20	73	44				10	
SCHED RECEIPTS																		
AVAILABLE	408-	433-	532-	719-	744-	769-	823-	866-	906-	936-	961-	1034-	1078-	1103-	1128-	1153-	1178-	1203-
PLANNED ORDERS								500										

	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	TOTALS
	2	25	54	43	40	30	20	73	44				10					
REQUIREMENTS																		2534
SCHED RECEIPTS																		61
AVAILABLE	1228-	1253-	1278-	1303-	1328-	1353-	1378-	1403-	1428-	1453-	1478-	1503-	1528-	1553-	1578-	1603-	1628-	1628-
PLANNED ORDERS								500										2000

896

APPENDIX I

Dynamic Order Quantities

The subject of lot sizing where requirements are discrete rather than continuous has just come into its own. A great many of the recent articles in the APICS Journal have covered the subject, none is more definitive than this article by Tom Gorham. We are including it in its entirety because it is in our opinion one of the basic reference works for lot sizing as used with a requirements planning program.

DYNAMIC ORDER QUANTITIES

Thomas Gorham
Outboard Marine Corp., Waukegan, Illinois

Computer capacity and techniques have now reached the point where more and more companies are developing time series requirements planning systems. In these systems the requirements for a part will be expressed not as a rate per day, but rather as an array of varying requirements scattered out through time. Components of stocked assemblies will show intermittent usage based on the expected building of the assembly. A seasonal part would show a fluctuating usage. It is apparent that such erratic requirements could not be validly expressed as a rate per day nor could they be ordered economically with either a fixed quantity or fixed time period order quantity calculation. An ordering system is required which will develop economical orders in spite of this changing and intermittent usage.

Two methods of calculating dynamic order quantities are discussed in this article. Both are non-reiterative in that they step through the array of requirements only a single time, calculating a series of orders. These methods are considerably faster than reiterative methods which must try several alternative strategies before deciding on an ordering pattern.

The first method which is more well known and the most commonly used, searches for the least unit cost. In developing an order it steps through the requirements calculating the cost of inventory and setup per piece and it orders at the point where the unit cost is lowest. This method, in spite of its apparently unassailable logic, turns out upon analysis and comparison with other methods of ordering, to be a very uneconomical way of determining order quantities. It develops ordering patterns which result in excessive inventory and also excessive setup charges.

The second method is newer and not so commonly known. It is based on the same theory as the classic EOQ formula, i.e., that the least total cost is at the point where the inventory cost and setup cost are equal. This method consistently develops ordering patterns which result in considerably smaller inventory and setup charges than does the least unit cost method.

*Reprinted from the First Quarter 1968 issue of the APICS *Production and Inventory Management Journal*.

The following examples show the difference in the way the two methods would order. They show a very simple array of requirements and the computation of order quantities using the least unit cost method. Throughout these examples we are assuming:

Unit cost = C = $1.00

Setup cost = S = $40.00

Inventory carrying cost = I = .5% per week (25% per year)

The inventory cost is figured as follows:

The first requirement of 1000 is assumed to come to stock and be drawn for the next usage in the same week. Therefore it would not acquire any inventory cost.

The second requirement of 6000 would be held in inventory for three weeks which is equivalent to carrying 18000 parts for one week. The 18000 at .5% gives an inventory cost of $90.00.

Week	Require-ments	Cum Reqts.	Weeks In Inv.	Reqts x Weeks	Inv. Cost @ .5%	Setup Cost	Total Cost	Unit Cost
1	1000	1000	0	0	0	40.00	40.00	.040
2			1					
3			2					
4	6000	7000	3	18000	90.00		130.00	.0186
5	1000	8000	4	4000	20.00		150.00	.0187

Figure 1

In the example of Figure 1, the least unit cost is at a quantity of 7000 where the unit cost is .0186 with a total cost of $130. An inspection of the costs, however, reveals that it would be less expensive to setup and make the requirements for 6000 separately since then there would be a setup charge for $40 rather than an inventory charge of $90. This would result in $50 less expense. The least total cost method would order this way because the inventory charge of $0 is closer to the setup charge than is $90. (There is no advantage to making part of the 6000 in order to achieve an exact balance of $40 inventory and $40 setup, since that would increase inventory but would not reduce setups.)

In Figure 2 the requirements have been switched around.

Week	Require-ments	Cum Reqts.	Weeks In Inv.	Reqts x Weeks	Inv. Cost @ .5%	Setup Cost	Total Cost	Unit Cost
1	6000	6000	0	0	0	40.00	40.00	.0067
2			1	0	0			
3			2	0	0			
4	1000	7000	3	3000	15.00		55.00	.0078
5	1000	8000	4	4000	20.00		75.00	.0094

Figure 2

Here the least unit cost is at a quantity of 6000 with a total cost of $40. Again, an analysis of the costs reveals that it would cost $40 to set up to make the 1000 in period 4 whereas if that quantity were combined with the initial requirement it would only cost $15 in inventory charges. This would be a savings of $25. The least total cost system would combine the 6000 in period 1 and the 1000 in period 4 (and more) because the cumulative inventory charges had not written off the setup charges.

These two examples, though admittedly rigged, do show the radical differences between these two methods. Many tests of these have been made using long arrays of requirements. A series of orders was developed and the resulting cost of inventory and setup was computed. The least unit cost method was very erratic in its behavior. On one set of requirements it would develop low setup costs and high inventory costs, and on another set it might do just the reverse. However it never could obtain the balance between the two which resulted in lower total costs than were being achieved by the least total cost method.

About the author —

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From a more mathematical point of view the following are generalized expressions of the two methods. (The derivations of these are in the appendix.) In these

S = Setup cost

C = Unit cost of part

I = Inventory carrying charge per period

R_n = Requirement quantity in period n

n = Number of periods ordered or period number

Least unit cost:

The unit cost at period n + 1 will be less if

$$nR_1 + (n-1)R_2 + (n-2)R_3 + \ldots + 2R_{n-1} + 1R_n < \frac{S}{IC}.$$

Therefore order cut through time periods until the expression on the left becomes greater than S/IC.

Least Total cost:

$$0R_1 + 1R_2 + 2R_3 + \ldots + (n-2)R_{n-1} + (n-1)R_n = \frac{S}{IC}.$$

Order at the point where the expression on the left is most nearly equal to S/IC.

Before going on, it might be a good idea to look at the expression S/IC which is the control factor in both formulas. This, in effect, defines a part from an economic standpoint since it contains setup cost, unit cost and the inventory carrying cost. Since this is a new concept, there has been no generally acceptable name developed for the expression, although "quantity factor" and "part-period" seem to be fairly well established. What this factor boils down to is the number of parts which if carried in inventory for one period would result in an inventory charge equal to the setup cost. In the previous examples S/IC would be \$40.00/.005 × \$1.00 = 8000, meaning that 8000 parts carried for one week (or 4000 parts for 2 weeks, etc.) would result in an inventory charge equal to the setup charge. This, I suspect, will become a very useful number in various inventory control applications.

To get back to the formulas, both expressions are related to S/IC. However, the weighting the requirements is completely reverse. Assume four time periods ($n=4$) in order to make the two expressions easier to read:

Least unit cost $- 4R_1 + 3R_2 + 2R_3 + 1R_4$.

Least total cost $- 0R_1 + 1R_2 + 2R_3 + 3R_4$.

The least unit cost puts a higher weight on the first requirement which is held in stock for much shorter time period than is the requirement for period five. This is not at all logical from a cost of inventory standpoint. On the other hand the weightings for the least total cost do seem to be more logical.

Another, probably even more disturbing, thing about the least unit cost formula is that it says that if the total at period n is less than S/IC, then the unit cost at $n + 1$ will be less regardless of quantity or inventory charges. This helps to understand why some of the orders developed by the least unit cost method are illogical as they were in Figures 1 and 2. As long as unit cost decreases it will order regardless of what it does to total cost.

In conclusion, the least unit cost method, in spite of its extremely attractive name and easily understood logic, actually does not develop orders which result in a low over-all cost. On the other hand, mathematical analysis and extensive comparative tests show that the least total cost system results in substantially lower costs of both inventory and setup. Although it is a little more complex in concept, it is equally simple to administer and use, and it certainly gives better results.

APPENDIX

Derivation of Formulas

1. *Formula for Least Unit Cost*

$$\text{Unit cost} = \frac{\text{Setup Cost} + \text{Inventory Cost}}{\text{Quantity}}$$

Setup cost = S

Inventory Cost = Requirement qty × weeks in Inventory × Cost of part × Inventory carrying cost.

Assuming that the first requirement is used as soon as it is received, the weeks in inventory would be zero. Then

$0R_1IC$ = cost of inventory for the first requirement

$1R_2IC$ = cost of inventory for the second requirement

$(n-1)R_nIC$ = cost of inventory for the n^{th} requirement

$nR_{n+1}IC$ = cost of inventory for the $n+1$ requirment

The total cost of inventory would be

$$0R_1IC + 1R_2IC + 2R_3IC = \ldots + (n-2)R_{n-1}IC + (n-1)R_nIC$$

or

$$[0R_1 + 1R_2 + 2R_3 + \ldots + (n-2)R_{n-1} + (n-1)R_n]IC$$

let $R_i = 0R_1 + 1R_2 + 2R_3 + \ldots + (n-2)R_{n-1} + (n-1)R_n$

Quantity is the sum of the requirements,

$$R_t = R_1 + R_2 + R_3 + \ldots + R_{n-1} + R_n$$

Thus unit cost at $n = \dfrac{S + R_iIC}{R_T}$

Unit cost at $n + 1 = \dfrac{S + R_iIC + n\,R_{n+1}IC}{R_T + R_{n+1}}$

Order R_{n+1} if unit cost is less than at R_n

Order R_{n+1} if

$$\frac{S + R_iIC + nR_{n+1}IC}{R_T + R_{n+1}} < \frac{S + R_iIC}{R_T}$$

This simplifies to

$$nR_TIC < S + R_iIC$$

$$nR_TIC - R_iIC < S$$

$$nR_T - R_i < \frac{S}{IC}$$

Substituting for R_T

$$nR_T = n(R_1 + R_2 + R_3 + \ldots + R_{n-1} + R_n)$$

$$nR_T = nR_1 + nR_2 + nR_3 + \ldots + nR_{n-1} + nR_n$$

$$R_i = 0R_1 + 1R_2 + 2R_3 + \ldots + (n-2)R_{n-1} + (n-1)R_n$$

$$nR_T - R_i = nR_1 + (n-1)R_2 + (n-2)R_3 + \ldots + 2R_{n-1} + 1R_n < \frac{S}{IC}$$

Order R_{n+1} if

$$nR_1 + (n-1)R_2 + (n-2)R_3 + \ldots + 2R_{n-1} + 1R_n < \frac{S}{IC}$$

2. *Least Total Cost*

This balances the cost of inventory with cost of setup.

Cost of Inv. = Cost of setup

$$R_iIC = S$$

$$R_i = \frac{S}{IC}$$

$$R_i = 0R_1 + 1R_2 + 2R_3 + \ldots + (n-2)R_{n-1} + (n-1)R_n = \frac{S}{IC}$$

APPENDIX II

Modifications to the IBM PICS Program

Acknowledgment

We'd like to thank Bruno Jobin, the Manager of Programming at Markem Corporation, Keene, New Hampshire, for supplying the following program steps for making modifications to the IBM System 360 PICS Requirements Planning Package so that it will print a projected available balance. We'd also like to thank Richard Danner, Manager of Systems Administration, for General Railway Signal Company, for his independent comments on this printout.

Modifying the IBM PICS Program to print a Projected Available Balance.

The MACRO listings from Markem Corporation are provided so that an experienced programmer can look at them and see what modifications must be made to produce a projected "On Hand Balance" print line. To achieve this, two MACROs must be altered. The MACROs are RPS3M (Phase-3Mainline) and RPSCP (print routine). The Coding modifications flagged in RPSCP (print routine) are straight forward and efficient. They can be included exactly as they appear. These instructions accommodate the extra line to be printed, which is identified by a print parameter code passed to the print routine by the RPS3M (Mainline MACRO).

The RPS3M MACRO is also straightforward and reasonably efficient. The purpose of these modifications is to calculate the projected on-hand balance line and to call the RPSCP (print MACRO) at the time the line is desired to print. The actual calculation of the projected on-hand balance is accomplished in lines RAEO4830 through RAEO5050. This code would have to be modified by each user to suit his own need.

Note that Markem carries their raw material on-hand balance (signified by MTYPN = 1 or 3) with more decimal position than the other material types. These instructions are included in their routine to compensate for this – lines RAEO4941 – RAEO4948. These instructions may not be of use to other companies.

It may be mentioned that the printer used to display the two MACROs did not have a Universal Character Set print chain. Therefore, it substituted the following:

(	printed as %
'	printed as @
)	printed as ¤
=	printed as #

It's important in looking at these MACROs that the programmer see where in the IBM program the modifications were made to make specific modifications to suit his own company's requirements rather than trying to duplicate the modifications that have been satisfactory for Markem Corporation.

Modifying the IBM PICS Program to Print a Projected Available Balance.

```
// JOB DISPLAY MACROS OF SYS/360 REQUIREMENTS PLANNING PROGRAMS          RPO00010
// EXEC SSERV                                                            RPO00020
```

```
I.RP53M V.M 0.0          164 BLOCKS          SYSTEM SOURCE-STATEMENT LIBRARY

         BRENO   I.RP53M

         MACRO                                                           RAE00010
         RP53M &OFFSETA,&PLANDAS,&NETREQT,&OPENORD,&LINEPLN,&ORDSSPJ,&SPRAE00020
               MEXIST                                                    RAE00030
*                                                                        RAE00040
*        RP53M     MAINLINE - PHASE THREE          3604-RF-051   V1-L0   RAE00050
*                  PRINT SEQUENTIAL                                      RAE00060
*----------------------------------------------------------------------  RAE00070
*                                                                        RAE00080
*                  PHASE 3 WILL PRINT THE DETAIL REQUIREMENTS GENERATION RAE00090
*        REPORT IN THE SEQUENCE OF THE ITEM MASTER FILE.                 RAE00100
*                                                                        RAE00110
*   REGISTER USAGE                                                       RAE00120
*                                                                        RAE00130
*        1         PASSES INFORMATION TO SUBROUTINES                     RAE00140
*        2         BASE FOR MAINLINE                                     RAE00150
*        3         BASE FOR COMMON AREAS                                 RAE00160
*        4         BASE FOR COMMON AREAS                                 RAE00170
*        11        BASE REGISTER                                         RAE00180
*        14        CALLING ROUTINE RETURN ADDRESS                        RAE00190
*                                                                        RAE00200
WS1001   BALR  2,0                                                       RAE00210
         USING *,2                                                       RAE00220
*                                                                        RAE00230
*  OPEN FILES                                                            RAE00240
         OPEN  APPRINT                                                   RAE00250
*                                                                        RAE00260
*  READ ITEM MASTER SEQUENTIALLY                                         RAE00270
*                                                                        RAE00280
WS1005   L     11,ARPMSEQA                                               RAE00290
         BALR  14,11                                                     RAE00300
*                                                                        RAE00310
*  IF END-OF-FILE, THE FOLLOWING BRANCH-INSTRUCTION WILL BE EXEC.        RAE00320
.*                                                                       RAE00330
         AIF   (&ACCONVPLN3 EQ 0).SKIP01                                 RAE00340
         B     WSEOF                                                     RAE00350
*                                                                        RAE00360
         AGO   .SKIP01A                                                  RAE00370
.SKIP01  B     WSEOJ                                                     RAE00380
*                                                                        RAE00390
.SKIP01A ANOP                                                            RAE00400
*  IF NOT END-OF-FILE DO THE FOLLOWING                                   RAE00410
         CLI   RPERRSW,X'00'          TEST IF ERROR SWITCH ON            RAE00420
         BE    WS1003                 IF NOT BRANCH TO PRINT TEST        RAE00430
         B     WS1150                 ELSE GO TO ERROR ROUTINE           RAE00440
*                                                                        RAE00450
         AIF   (&ACCONVPLN3 EQ 0).SKIP02                                 RAE00460
*                                                                        RAE00470
*  EOF-HANDLING                                                          RAE00480
*                                                                        RAE00490
WSEOF    CLI   PARPLALL,X'F1'         TEST IF PRINT-ALL-ACT.-PARAM. ON   RAE00500
         BNE   WSEOJ                  IF NOT BRANCH TO END-OF-JOB-ROUT   RAE00510
         CLI   PARRENTY,X'40'         TEST IF RE-ENTRY PARAM. OFF        RAE00520
         BE    WSEOJ                  IF YES BRANCH TO END-OF-JOB-ROUT   RAE00530
         MVI   PARINTER,X'40'         TURN OFF INTERRUPT AND             RAE00540
         MVI   PARRENTY,X'40'         RE-ENTRY PARAMETERS AND            RAE00550
         B     WS1005                 BRANCH TO SEQUENT. READ            RAE00560
.*                                                                       RAE00570
.*                                                                       RAE00580
.SKIP02  ANOP                                                            RAE00590
*                                                                        RAE00600
*  TEST IF THIS RECORD IS TO BE PRINTED                                  RAE00610
*                                                                        RAE00620
WS1003   CLI   PARPRINT,X'F1'         TEST IF ALL RECORDS SHOULD BE      RAE00630
         BE    WS1010                 PRINTED. IF YES BRANCH TO PRINT    RAE00640
.*                                                                       RAE00650
         AIF   (&ACCONVPLN3 EQ 0).SKIP03                                 RAE00660
.*                                                                       RAE00670
         CLI   PARINTER,X'F1'         TEST IF INTERUPT PARAM. ON         RAE00680
         BE    WS1015                 IF YES BRANCH INTERRUPT BIT TEST   RAE00690
         CLI   PARRENTY,X'40'          TEST RE-ENTRY PARAMETER           RAE00700
         BNE   WS1015                  IF ON BRANCH INTERRUPT BIT TEST   RAE00710
.*                                                                       RAE00720
.SKIP03  ANOP                                                            RAE00730
.*                                                                       RAE00740
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE00744
*  THIS ROUTINE WHICH REPLACES RAE00750-760-770 PRINTS ONLY THOSE ITEMS  RAE00745
*  WHICH HAVE GENERATED AN EXCEPTION NOTICE - DESIGNATED BY A FLAG IN    RAE00746
*  MRPF.  IT ALSO RESETS TAIPNMRA TO BLANKS.                             RAE00747
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE00748
         MVC   TAIPNMRA,=X'4040404040'  BLANK NEXT ADDRESS               RAE00750
         CLC   MRPF,SWMRPF             EXCEPTION NOTICE WRITTEN          RAE00751
         BE    CLEAR              YES - CLEAR FLAG                       RAE00752
         BAL   14,REWRITE         NO - REWRITE ITEM MASTER               RAE00753
         B     WS1005             READ NEXT SEQUENTIAL RECORD            RAE00754
CLEAR    MVI   MRPF,X'00'         RESET REQUIREMENT PLANNING FLAG        RAE00755
         BAL   14,REWRITE         REWRITE ITEM MASTER                    RAE00756
         B     WS1010                                                    RAE00757
REWRITE  ST    14,HOLD14           SAVE ADDRESS OF REG 14                RAE00758
         L     11,ARAMSEQU        LOAD ADDRESS OF I/M SEQ WRITE          RAE00759
         BALR  14,11              BRANCH TO WRITE                        RAE00760
         CLI   RPERRESW,X'FF'      TEST IF ERRORS IS NONE.               RAE00761
         BNE   BP14                GO TO BRANCH THRU REG 14              RAE00762
*                                                                        RAE00763
*  ERROR ON REWRITE                                                      RAE00764
*                                                                        RAE00765
         MVC   ERRCODE,WSERRI          LOAD WRITE ERROR CODE             RAE00766
         B     WS1200              GO TO TYPE                            RAE00767
BP14     L     14,HOLD14          RESTORE REG 14                         RAE00768
         BR    14                 RETURN TO MAINLINE                     RAE00770
         AIF   (&ACCONVPLN3 EQ 0).SKIP04                                 RAE00780
WS1015   TM    MRPF,X'40'                TEST IF INTERRUPT BIT ON IF NOT RAE00790
         BZ    WS1005                    READ NEXT SEQ. REC. ELSE PRINT  RAE00800
.*                                                                       RAE00810
.SKIP04  ANOP                                                            RAE00820
.*                                                                       RAE00830
*                                                                        RAE00840
*  PRINT THIS RECORD                                                     RAE00850
*                                                                        RAE00860
```

```
*      A. PRINT INDICATIVE                                                RAE00870
*                                                                         RAE00880
WS1010   L     11,APT1001               LOAD ADDR OF PRINT INDICATIVE    RAE00890
         BALR  14,11                    BRANCH AND LINK TO RPSPT         RAE00900
.*                                                                        RAE00910
.*  MACRO DEC. IS SUBORD. MSTR READ TO BE INCLUDED                       RAE00920
.*                                                                        RAE00930
         AIF   ('&RESMERSTR' NE 'SUB').SKIP04A                           RAE00940
*                                                                         RAE00950
*  READ SUBORDINATE MASTER                                               RAE00960
*                                                                         RAE00970
         L     11,ARPRAND                                                RAE00980
         BALR  14,11                                                     RAE00990
*                                                                         RAE01000
* ERROR HANDLING ON S/M READ AND WRITE IS DONE EXTERNAL TO THIS PHASE    RAE01010
*                                                                         RAE01020
.SKIP04A ANOP                                                            RAE01030
*                                                                         RAE01040
*    B. PRINT DATE HEADER                                                RAE01050
*                                                                         RAE01060
WS1013   L     11,ACP1001                LOAD ADDRESS OF PRINT ROUTINE    RAE01070
         LA    1,6                       LOAD PRINT CODE FOR DATE        RAE01080
         BALR  14,11                     BRANCH AND LINK TO RPSCP        RAE01090
         CLI   MULTPSW,X'00'             IS MULT.PRT SWITCH ON           RAE01100
         BNE   WS1021                                                    RAE01110
*                                                                         RAE01120
* INITIALIZE AND PRINT GROSS                                             RAE01130
*                                                                         RAE01140
         L     11,AIG1001                LOAD ADDRESS OF INIT. GROSS     RAE01150
         LA    1,GROSSQTY                LOAD ADDRESS OF WORKAREA        RAE01155
         BALR  14,11                                                     RAE01156
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE01160
* A WEEKLY AVERAGE USAGE FIGURE IS ADDED INTO EACH TIME PERIOD FOR       RAE01161
* FIXED QUANTITY ITEMS TO REFLECT REPAIR PARTS.  HOWEVER, IF THE ON      RAE01162
* HAND INVENTORY IS GREATER THAN THE AVERAGE, THE AVERAGE IS NOT ADDED  RAE01163
* INTO THE FIRST PERIOD WHICH IS THE SOLE PAST DUE PERIOD.              RAE01164
* THIS ROUTINE IS ALSO IN RPSZM - RAD02090 THRU 2119,                   RAE01165
* RAE01161 THRU 1189.                                                    RAE01166
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE01167
         CLI   MOPOC,C'3'               FIXED ORDER QTY                  RAE01168
         BE    USEAVE3                     YES                           RAE01169
         CLI   MOPOC,C'6'                  USEAVS ROUTINE                RAE01170
         BNE   GETOUT3M                 NO - RETURN TO MAINLINE          RAE01171
USEAVE3  ZAP   HOLDFA3,MSUFA  SERVICE USAGE 1ST AVE. TO WORK AREA       RAE01172
         AP    HOLDFA3,=P'5'           HALF ADJUST                      RAE01173
         MVO   HOLDFA3,HOLDFA3(2)       DROP DECIMAL PLACE               RAE01174
         ST    7,RPJSAVE7               SAVE REGISTERS                   RAE01175
         ST    8,RPJSAVE8                                                RAE01176
         LA    7,GROSSQTY               ADDRESS OF WORK AREA             RAE01177
         CP    MOHAND,HOLDFA3           AVERAGE USAGE TO ON HAND         RAE01178
         BH    NOTFIRST        ON HAND HIGH - NO 1ST AVE. IN PAST DUE   RAE01179
         LH    8,NUMTHREE               LOAD LOOP CONTROL - 52 PERIODS   RAE01180
         B     LOOP3                                                     RAE01181
NOTFIRST LA    7,L'GROSSQTY(7)          MOVE POINTER TO CURRENT PERIOD   RAE01182
         LH    8,=H'51'                 LOAD LOOP CONTROL - 51 PERIODS   RAE01183
LOOP3    AP    0(L'GROSSQTY,7),HOLDFA3   ADD AVERAGE USAGE               RAE01184
```

```
         LA    7,L'GROSSQTY(7)          POINT TO NEXT FIELD              RAE01185
         BCT   8,LOOP3                  TEST END OF LOOP                 RAE01186
         L     7,RPJSAVE7               RESTORE REGISTERS                RAE01187
         L     8,RPJSAVE8                                                RAE01188
GETOUT3M DS    0H                       BRANCH POINT                     RAE01189
.*                                                                        RAE01190
.*  TEST IF GROSS IS TO BE PROJECTED                                     RAE01195
.*                                                                        RAE01200
         AIF   ('&GROSSPJR' EQ 'NO').SKIP05                              RAE01210
         L     11,APJ1001                LOAD ADDRESS OF PROJECT GROSS    RAE01220
         BALR  14,11                     AND BRANCH TO RPSPJ             RAE01230
.SKIP05  ANOP                                                            RAE01240
.*                                                                        RAE01250
.*                                                                        RAE01260
WS1021   CLI   PRTGROSS,X'F1'            TEST IF GROSS IS TO BE PRINTED   RAE01270
         AIF   ('&OFFSETRR' EQ 'NO').SKIP06                              RAE01280
         BNE   WS1022                    IF NOT CONTINUE TESTING         RAE01290
         AGO   .SKIP07                                                   RAE01300
.SKIP06  BNE   WS1030                    IF NOT, CONTINUE TESTING        RAE01310
.SKIP07  L     11,ACP1001                LOAD ADDRESS OF PRINT ROUTINE    RAE01320
         LA    1,1                       LOAD PRINT CODE FOR GROSS       RAE01330
         BALR  14,11                     AND BRANCH TO RPSCP             RAE01340
*                                                                         RAE01350
*  TEST IF GROSS ONLY                                                    RAE01360
*                                                                         RAE01370
         CLI   PRAGROSS,X'F1'            IS THIS GROSS ONLY              RAE01380
         BE    WS1100                    IF YES BRANCH TO END OF ROUTINE  RAE01390
.*                                                                        RAE01400
.* MACRO DEC. HAS OFFSETRRYES SPECIFIED, IF NOT SKIP CODE TIL .SKIP08    RAE01410
.*                                                                        RAE01420
         AIF   ('&OFFSETRR' EQ 'NO').SKIP08                              RAE01430
*                                                                         RAE01440
*  TEST IF GROSS IS TO BE OFFSETTED                                      RAE01450
*                                                                         RAE01460
WS1022   CLI   PRAGROSS,X'F1'            TEST IF GROSS ONLY              RAE01470
         BE    WS1030                    IF YES, NO OFFSET               RAE01480
         CLI   PARNET,X'40'              TEST FOR NET OFF                RAE01490
         BNE   WS1030                    IF ON, NO OFFSET                RAE01500
         CLI   PARPLAN,X'40'             TEST FOR PLANNED ORDERS OFF     RAE01510
         BNE   WS1030                    IF ON, NO OFFSET                RAE01520
         CLI   PAROFFST,X'40'            TEST FOR OFFSET OFF             RAE01530
         BE    WS1030                    IF OFF, NO OFFSET               RAE01540
* TEST IF OFFSETTED GROSS IS TO BE PRINTED                               RAE01550
         CLI   PRTOFSET,X'F1'            TEST IF PRINT OFFSET ON         RAE01560
         BNE   WS1100                    IF NOT BRANCH TO END OF ROUTINE  RAE01570
*                                                                         RAE01580
*  OFFSET AND PRINT GROSS REQUIREMENT                                    RAE01590
*                                                                         RAE01600
WS1023   CLI   MULTPSW,X'00'             TEST IF OFFSET DONE             RAE01610
         BNE   WS1025                    IF YES SKIP TO PRINT            RAE01620
         L     11,AOR1001                LOAD ADDRESS OF OFFSET ROUTINE   RAE01630
         LA    1,GROSSQTY                LOAD ADDRESS OF OFFS. INPUT AREA RAE01640
         BALR  14,11                     BRANCH TO OFFSET                RAE01650
WS1025   L     11,ACP1001                LOAD ADDRESS OF PRINT ROUTINE    RAE01660
         LA    1,5                       LOAD PRINT CODE FOR OFFSET      RAE01670
         BALR  14,11                     BRANCH TO PRINT                 RAE01680
```

```
         B     WS1100                      AFTER PRINT NA TO END OF ROUTINE RAE01690
*                                                                       RAE01700
.SKIP08  ANOP                                                           RAE01710
*                                                                       RAE01720
*  TEST IF OPEN ORDERS ON NET IS TO BE PRINTED                          RAE01730
*                                                                       RAE01740
*                                                                       RAE01750
*  INITIALIZE AND PRINT OPEN ORDERS                                     RAE01760
*                                                                       RAE01770
WS1010   CLI   PRIOPORD,X'40'              TEST OPEN ORDERS IS TO BE PRINTED RAE01780
         BE    WS1070                      IF NO, TEST NET              RAE01790
         AIF   ('&LOPENORD' EQ 'NO').SKIP09                             RAE01800
         CLI   MULTPSW,X'00'               TEST INIT. OPEN ORDERS ROUT.DONE RAE01810
         BNE   WS1035                      IF YES BRANCH TO PRINT ELSE  RAE01820
         L     11,AIO1001                  LOAD ADDR OF INIT OPEN ORDERS RAE01830
         BALR  14,11                       BRANCH TO RPSIO              RAE01840
         MVI   WSINOSW,X'FF'               OPN ORDRS HAVE BEEN INITIALIZED RAE01850
WS1035   L     11,ACP1001                  LOAD ADDRESS OF PRINT ROUTINE RAE01860
         LA    1,2                         LOAD PRINT CODE FOR OPEN ORDERS RAE01870
         BALR  14,11                       BRANCH TO PRINT              RAE01880
.SKIP09  ANOP                                                           RAE01890
         AIF   ('&NETREQTA' NE 'YES').SKIP10                            RAE01900
         CLI   PRTNET,X'40'                TEST IF NET IS TO BE PRINTED RAE01910
         BNE   WS1050                      IF YES BRANCH TO CALC. NET   RAE01920
.*                                                                      RAE01930
.*                                                                      RAE01940
         B     WS1072                      ELSE BRANCH AWAY             RAE01950
WS1050   CLI   MULTPSW,X'00'               TEST NET ALREADY CALCULATED  RAE01960
         BNE   WS1055                      IF YES SKIP NET CALCULATION  RAE01970
WS1052   L     11,ACN1001                  LOAD ADDR. OF CALCULATE NET ROUT RAE01980
         BALR  14,11                       BRANCH TO NET                RAE01990
WS1055   CLI   NTNTSW,X'FF'                TEST IF NET SWITCH ON        RAE02000
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RAE02007
* RAE02010 CHANGED TO PRINT RUNNING ON HAND BALANCE.                    RAE02008
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RAE02009
         BNE   00ADU1                                                   RAE02010
         L     11,ACP1001                  LOAD ADDRESS OF PRINT ROUTINE RAE02020
         LA    1,3                         LOAD PRINT CODE FOR NET      RAE02030
         BALR  14,11                       BRANCH TO PRINT              RAE02040
.*                                                                      RAE02050
.SKIP10  ANOP                                                           RAE02060
*  TEST IF NET IS TO BE OFFSETTED                                       RAE02070
*                                                                       RAE02080
WS1060   CLI   PARNET,X'40'                TEST FOR NET OFF             RAE02090
         BE    WS1066                      IF OFF, DO NOT OFFSET        RAE02100
         CLI   PARPLAN,X'40'               TEST FOR PLANNED ORDERS OFF  RAE02110
         BNE   WS1066                      IF ON, NO OFFSET             RAE02120
         CLI   PAROFFST,X'40'              TEST FOR OFFSET PARAM OFF    RAE02130
         BE    WS1066                      IF OFF, NO OFFSET            RAE02140
* TEST IF OFFSETTED NET IS TO BE PRINTED                                RAE02150
         CLI   PRTOFSET,X'F1'              TEST IF OFFSET IS TO BE PRINTED RAE02160
         BNE   WS1100                      IF NOT BRANCH TO END OF ROUTINE RAE02170
         AIF   ('&OFFSETRQ' EQ 'NO').SKIP10A                            RAE02180
         AIF   ('&NETREQTA' EQ 'NO').SKIP10A                            RAE02190
         CLI   MULTPSW,X'FF'               ELSE TEST IF OFFSET NET DONE RAE02200
         BE    WS1078                      IF YES GO TO PRINT OFFSET    RAE02210
         B     WS1076                      IF NO, GO TO CALC OFFSET     RAE02220
         AGO   .SKIP10B                                                 RAE02230
.SKIP10A B     WS1100                      BRANCH TO END OF ROUTINE     RAE02240
.SKIP10B ANOP                                                           RAE02250
WS1066   CLI   PARPLAN,X'F1'               PLANNED ORDERS TO BE STORED  RAE02260
         BNE   WS1200                      IF NO, GO TO END OF ROUTINE  RAE02270
         B     WS1080                      ELSE MAKE FURTHER TESTS      RAE02280
WS1070   CLI   PRTNET,X'40'                TEST IF NET PARAM IS OFF     RAE02290
         BE    WS1072                      IF OFF, TEST OFFSET          RAE02300
         AIF   ('&LOPENORD' EQ 'NO').SKIP11                             RAE02310
         AGO   .SKIP12                                                  RAE02320
.SKIP11  AIF   ('&NETREQTA' EQ 'NO').SKIP16                             RAE02330
.SKIP12  CLI   MULTPSW,X'FF'               TEST IF OPEN ORDS HAVE BEEN INIT RAE02340
         AIF   ('&NETREQTA' EQ 'NO').SKIP13                             RAE02350
         BE    WS1055                      YES, TEST NET                RAE02360
         AGO   .SKIP14                                                  RAE02370
.SKIP13  BE    WS1060                      YES, TEST NET OFFSET         RAE02380
.SKIP14  AIF   ('&LOPENORD' EQ 'NO').SKIP15                             RAE02390
         L     11,AIO1001                  LOAD ADDR OF INIT OPEN ORDS  RAE02400
         BALR  14,11                       BRANCH AND LINK TO RPSIO     RAE02410
*                                                                       RAE02420
.SKIP15  AIF   ('&NETREQTA' EQ 'NO').SKIP16                             RAE02430
         B     WS1052                      BRANCH TO CALC NET           RAE02440
         AGO   .SKIP17                                                  RAE02450
.SKIP16  B     WS1060                      BRANCH TO TEST NET OFFSET    RAE02460
.SKIP17  ANOP                                                           RAE02470
* CHECK IF NET IS TO BE OFFSET                                          RAE02480
WS1072   CLI   PARNET,X'40'                TEST IF NET IS OFF           RAE02490
         BE    WS1066                      IF OFF, NO OFFSET            RAE02500
         CLI   PARPLAN,X'40'               TEST IF PLANNED ORDERS IS OFF RAE02510
         BNE   WS1066                      IF ON, NO OFFSET             RAE02520
         CLI   PAROFFST,X'40'              TEST IF OFFSET IS OFF        RAE02530
         BE    WS1066                      IF OFF, NO OFFSET            RAE02540
         CLI   PRTOFSET,X'40'              TEST IF PRINT OFFSET IS ON   RAE02550
         BE    WS1100                      IF NOT, GO TO END OF ROUTINE RAE02560
         CLI   MULTPSW,X'FF'               HAS OFFSET BEEN CALCULATED   RAE02570
         AIF   ('&NETREQTA' EQ 'NO').SKIP17A                            RAE02580
         AIF   ('&OFFSETRQ' EQ 'YES').SKIP18                            RAE02590
.SKIP17A BE    WS1100                      YES, GO TO END OF ROUTINE    RAE02600
         AGO   .SKIP19                                                  RAE02610
.SKIP18  BE    WS1078                      YES, PRINT OFFSET            RAE02620
.SKIP19  AIF   ('&LOPENORD' EQ 'NO').SKIP21                             RAE02630
         CLI   WSINOSW,X'FF'               CHK IF OPEN ORDERS INITIATED RAE02640
.SKIP20  AIF   ('&NETREQTA' EQ 'NO').SKIP21                             RAE02650
         BE    WS1074                      YES, CALC NET                RAE02660
         AGO   .SKIP22                                                  RAE02670
.SKIP21  BE    WS1100                      YES, GO TO END OF ROUTINE    RAE02680
.SKIP22  L     11,AIO1001                  LOAD ADDR OF INIT OPEN ORDERS RAE02690
         BALR  15,11                       BRANCH AND LINK TO RPSIO     RAE02700
*                                                                       RAE02710
.SKIP23  AIF   ('&NETREQTA' EQ 'NO').SKIP24                             RAE02720
WS1074   L     11,ACN1001                  LOAD ADDR OF CALC NET        RAE02730
         BALR  14,11                       BRANCH AND LINK TO RPSCN     RAE02740
*                                                                       RAE02750
         CLI   NTNTSW,X'FF'                TEST NET SWITCH              RAE02760
         BNE   WS1100                      OFF, GO TO END OF ROUTINE    RAE02770
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                                                                        RAE02780
.*                                                                      RAE02790
         AIF   (&LCOFFSETRA EQ 'NO').SKIP24                             RAE02800
WS1036   L     11,AOR1001              LOAD ADDR OF OFFSET ROUTINE      RAE02810
         LA    1,NCTOIY                LOAD ADDRESS OF OFFS INP AREA    RAE02820
         BALR  14,11                   BRANCH AND LINK TO RPSOR         RAE02830
*                                                                       RAE02840
WS1076   L     11,ACP1001              LOAD ADDR OF PRINT ROUTINE       RAE02850
         LA    1,5                     PASS PRINT OFFSET INDICATOR      RAE02860
         BALR  14,11                   BRANCH AND LINK TO RPSCP         RAE02870
.SKIP24  B     WS1100                  BRANCH TO END OF ROUTINE         RAE02880
*                                                                       RAE02890
*   TEST IF PLANNED ORDERS IS TO BE ACCOMPLISHED                        RAE02900
*                                                                       RAE02910
         AIF   (&ACPLANORSI EQ 'NONE').SKIP26                           RAE02920
WS1080   CLI   PRTPLORD,X'F1'  TEST IF PRINT PLAN ORDERS PARAM. ON      RAE02930
         BE    WS1085                  IF YES SKIP OFFSET               RAE02940
         AIF   (&LCOFFSETRA EQ 'NO').SKIP25                             RAE02950
         CLI   PRTOFSET,X'40'          TEST IF PRINT OFFSET PARAM. ON   RAE02960
         BE    WS1100                  IF NOT GO TO END OF THIS ROUTINE RAE02970
         CLI   MULTPSW,X'FF'           TEST IF OFFSET DONE              RAE02980
         BE    WS1090                  IF YES SKIP OFFSET ELSE          RAE02990
         L     11,AIP1001              LOAD ADDRESS OF RPSIP            RAE03000
         LA    1,OSETOIY               LOAD ADDRESS OF OUTPUT AREA      RAE03010
         BALR  14,11                   BRANCH TO RPSIP                  RAE03020
WS1090   L     11,ACP1001               LOAD ADDRESS OF PRINT ROUTINE   RAE03030
         LA    1,3                     LOAD PRINT CODE FOR OFFSET       RAE03040
         BALR  14,11                   BRANCH TO PRINT AND THEN         RAE03046
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   RAE03047
* CHANGED RAE03030 TO BRANCH TO OWN ROUTINE TO ESTABLISH DUE DATES OF   RAE03048
* OFFSET PLANNED ORDERS AND TO COMPUTE A RUNNING ON HAND BALANCE.       RAE03049
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   RAE03050
.SKIP25  B     OOPOUT         USERS ROUTINE                             RAE03060
*                                                                       RAE03070
*   INITIALIZE AND PRINT PLANNED ORDERS                                 RAE03080
*                                                                       RAE03090
WS1085   CLI   MULTPSW,X'FF'           TEST IF RPSIP DONE               RAE03100
         BE    WS1086                  IF YES, SKIP IT ELSE             RAE03110
         L     11,AIP1001              LOAD ADDRESS OF RPSIP            RAE03120
         LA    1,PLORDOIY              LOAD ADDRESS OF OUTPUT AREA      RAE03130
         BALR  14,11                   BRANCH TO RPSIP                  RAE03140
WS1086   L     11,ACP1001               LOAD ADDRESS OF PRINT ROUTINE   RAE03150
         LA    1,4                     LOAD PRINT CODE FOR P/O          RAE03160
         BALR  14,11                   BRANCH TO PRINT                  RAE03170
         AGO   .SKIP27                                                  RAE03180
.*                                                                      RAE03190
.SKIP26  ANOP                                                           RAE03200
WS1080   EQU   *                                                        RAE03210
.SKIP27  ANOP                                                           RAE03220
*                                                                       RAE03230
*   END-OF-ROUTINE HANDLING                                             RAE03240
*                                                                       RAE03250
WS1100   MVI   MULTPSW,X'FF'           SET MULT. PRINT SWITCH ON        RAE03260
         CLI   MLTENDSW,X'FF'          TEST IF MULT. PRINT END SW. ON   RAE03270
         BNE   WS1011                  IF NOT BRANCH BACK FOR NEXT LIN  RAE03280
         MVI   MULTPSW,X'00'           ELSE TURN OFF MULTPSW AND        RAE03290
         MVI   MLTENDSW,X'00'          MULT ENDS AND                    RAE03300
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                                                                        RAE03300
         MVI   MENTSW,X'00'            MENT SWITCH OFF                  RAE03310
.*                                                                      RAE03320
.*  MACRO DEC. IF CONVPLN = NO, SKIP CODE TIL SKIP28                    RAE03330
.*                                                                      RAE03340
         AIF   (&LCCONVPLNA EQ 'NO').SKIP28                             RAE03350
         CLI   PARINTER,X'F1'          TEST IF INTERRUPT PARAM. ON      RAE03360
         BE    WS11004                 GO TEST MENT 2ND BIT             RAE03370
         CLI   PARRENTY,X'40'          TEST RE-ENTRY PARAMETER          RAE03380
         BE    WS1005                  NOT ON GO GET NEXT RECORD.       RAE03390
WS11004  TM    MENT,X'40'              TEST IF S/M INTERRUPT BIT ON     RAE03400
         BZ    WS1005                  IF NOT BRANCH BACK FOR NEXT REC. RAE03410
         NI    MENT,X'BF'              TURN OFF INTERRUPT BIT IN S/M    RAE03420
*                                                                       RAE03430
*   WRITE ITEM MASTER                                                   RAE03440
*                                                                       RAE03450
         L     11,ARPMSEQU             LOAD ADDRESS OF S/M SEQ WRITE    RAE03460
         BALR  14,11                   BRANCH TO WRITE                  RAE03470
         CLI   RPCRRNSW,X'FF'          TEST FOR LANDRS. IF NONE,        RAE03480
         BNE   WS1005                   BRANCH BACK FOR NEXT RECORD     RAE03490
*                                                                       RAE03500
*   ERROR HANDLING ROUTINES                                             RAE03510
*                                                                       RAE03520
         MVC   ERRCODE,WSERR1          LOAD WRITE ERROR CODE            RAE03530
         B     WS1200                  GO TO TYPE                       RAE03540
         AGO   .SKIP29                                                  RAE03550
.SKIP28  ANOP                                                           RAE03560
         B     WS1005                  BRANCH TO READ ANOTHER RECORD    RAE03570
.SKIP29  ANOP                                                           RAE03580
WS1150   MVC   ERRCODE,WSERR2          LOAD READ ERROR CODE             RAE03590
         B     WS1200                  GO TO TYPE                       RAE03600
         AIF   (&LCSMERISTA NE 'ICO').SKIP30                            RAE03610
*   ON A S/M READ ERROR, TYPE MSG AND GO TO READ ANOTHER RECORD         RAE03620
SMERROR  MVC   ERRCODE,WSERR3          LOAD S/M ERROR CODE              RAE03630
.SKIP30  ANOP                                                           RAE0363[illegible]
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *       RAE03637
* KEY MUST BE UNPACKED FOR CONSOLE ERROR MESSAGE. RAE03640.              RAE03638
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *       RAE03639
WS1200   UNPK  ERITEMNO,ISMPN          MOVE ITEM NUMBER TO PRINT        RAE03640
         L     11,ATYPEOUT             LOAD ADDR OF ERROR TYPING RTN    RAE03650
         BALR  14,11                   BRANCH AND LINK TO TYPEOUT       RAE03660
         B     WS1005                  BRANCH TO READ ANOTHER RECORD    RAE03670
*                                                                       RAE03680
*   END-OF-JOB ROUTINE                                                  RAE03690
*                                                                       RAE03700
*   1. CLOSE ITEM MASTER FILE                                           RAE03710
*                                                                       RAE03720
WSEOJ    MVC   MSPI,MTCLOSE                                             RAE03730
         L     11,ARPMCALI                                              RAE03740
         BALR  14,11                                                    RAE03750
*                                                                       RAE03760
.*                                                                      RAE03770
.*  IF NO SUBORD. MASTER FILE, SKIP CODE TIL SKIP31                     RAE03780
.*                                                                      RAE03790
         AIF   (&LCSMEXISTA NE 'ICO').SKIP31                            RAE03800
*   2. CLOSE SUBORD. MASTER FILE                                        RAE03810
*                                                                       RAE03820
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                                                                   RAE03830
         MVC   SWPT,MTCLOSE                                        RAE03840
         L     11,ARPRCALT                                         RAE03850
         BALR  14,11                                               RAE03860
.SKIP31  ANOP                                                      RAE03870
.*                                                                 RAE03880
*                                                                  RAE03890
*  5. CLOSE EXCEPTION FILE                                         RAE03900
*                                                                  RAE03910
         L     11,ADFEDERC                                         RAE03920
         BALR  14,11                                               RAE03930
*                                                                  RAE03940
*  6. CLOSE PRINTER                                                RAE03950
*                                                                  RAE03960
         CLOSE APPRINT                                             RAE03970
*                                                                  RAE03980
*  TYPE OUT END-OF-JOB MESSAGE                                     RAE03990
*                                                                  RAE04000
         MVI   EMAREA,C' '         CLEAR TYPE MSG AREA             RAE04010
         MVC   EMAREA+1(L'EMAREA-1),EMAREA                         RAE04020
         MVC   EMMESG(L'EMEOJ),EMEOJ  MOVE EOJ MSG TO AREA         RAE04030
         L     11,ATYPEOUT         LD ADDR OF TYPE ROUTINE         RAE04040
         BALR  14,11               BRANCH AND LINK TO TYPEOUT      RAE04050
*                                                                  RAE04060
         EOJ                                                       RAE04070
*                                                                  RAE04080
*  CONSTANTS ASSOCIATED WITH MAINLINE 3                            RAE04090
*                                                                  RAE04097
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE04098
* LENGTH ATTRIBUTE CHANGED FROM 132, RAE04100S                     RAE04099
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE04100
APPRTIO4 DS    CL120               PRINTER OUTPUT AREA             RAE04110
WSTNOSW  DC    X'00'               SW TO INDICATE APVIC HAS BEEN PERFORMED RAE04120
WSERR1   DC    C'31'               ERROR FOUND WHILE WRITING ITEM MASTER   RAE04130
WSERR2   DC    C'32'               ERROR FOUND WHILE READING ITEM MASTER   RAE04140
WSERR3   DC    C'33'               SUBORDINATE MASTER ERROR, READ NEXT RECORD RAE04141
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE04142
* HOLD AREAS AND CONSTANTS. REFER TO RAC01170 THRU 1189. RAD04145-4143. RAE04143
* HOLD AREAS. REFER TO RAE00750 THRU 0770.  RAE04145.              RAE04144
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE04145
WS1      DC    H'513'                                              RAE04146
HOLDFA3  DC    PL3'00'             TO HOLD FIRST AVERAGE           RAE04147
P3SAV17  DS    F                   TO HOLD REG 7                   RAE04148
P3SAVE8  DS    F                   TO HOLD REG 8                   RAE04149
SWRPF    DC    X'FF'               TO TEST FOR EXCEPTION NOTICE    RAE04149
HOLD14   DS    F                   TO HOLD REG 14                  RAE04150
*                                                                  RAE04160
*  TABLE OF ADDRESS CONSTANTS - FOR LINKAGE TO I/O AND PROCESSING  RAE04170
*                              ROUTINES IN PHASE 3 ONLY-           RAE04180
*                                                                  RAE04195
*  TEST IF S/M FILE EXISTS                                         RAE04200
         AIF   ('&CSMEXIST' NE 'Y').M3AT1                          RAE04210
ARPRRAND DC    A(RPRRANDR)   READ S/M                              RAE04220
ARPRUPDW DC    A(RPRUPDWR)   WRITE S/M                             RAE04230
.M3AT1   ANOP                                                      RAE04240
AIG1001  DC    A(IG1001)           INITIALIZE GROSS ROUTINE        RAE04250
APT1001  DC    A(PT1001)           PRINT INDICATIVE ROUTINE
ACP1001  DC    A(CP1001)           PRINT ROUTINE                   RAE04260
         AIF   ('&CGROSSPJ' EQ 'NO').M3AT2                         RAE04270
APJ1001  DC    A(PJ1001)           PROJECT GROSS REQUIREMENTS ROUTINE RAE04280
.M3AT2   AIF   ('&COPENORD' EQ 'NO').M3AT3                         RAE04290
AIO1001  DC    A(IO1001)           INITIALIZE OPEN ORDER BUCKETS ROUTINE RAE04300
.M3AT3   AIF   ('&CPLANORD' EQ 'NO').M3AT4                         RAE04310
AIP1001  DC    A(IP1001)           INITIALIZE PLANNED ORDER BUCKETS ROUTINE RAE04320
.M3AT4   AIF   ('&COFFSETRQ' EQ 'NO').M3AT5                        RAE04330
AOR1001  DC    A(OR1001)           CALCULATE OFFSET ROUTINE        RAE04340
.M3AT5   AIF   ('&CNETREQ' EQ 'NO').M3AT6                          RAE04350
ACN1001  DC    A(CN1001)           CALCULATE NET ROUTINE           RAE04360
.M3AT6   ANOP                                                      RAE04370
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE04400
* ROUTINE TO ESTABLISH DUE DATES OF OFFSET PLANNED ORDERS.          RAE04410
* RAE04400 THRU RAE04790.                                          RAE04420
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE04430
ODRDUT   CLI   MOLTPSW,X'FF'       IS OFFSET DONE                  RAE04480
         BE    OSDONE              YES                             RAE04481
         ST    5,RWSAVE5           SAVE REGISTERS                  RAE04485
         ST    6,RWSAVE6                                           RAE04490
         ST    7,RWSAVE7                                           RAE04500
         ST    8,RWSAVE8                                           RAE04510
         ST    9,RWSAVE9                                           RAE04520
         LH    5,NUMTMPER          TOTAL TIME PERIODS              RAE04530
         ZAP   HOLDLT,MLTME        LEAD TIME IN WEEKS TO HOLD      RAE04535
         CVB   6,HOLDLT            CONVERT TO BINARY               RAE04540
         LA    7,OSETQTY           OFFSET PLANNED ORDERS           RAE04550
         LA    8,PLORDQTY          PLANNED ORDERS DUE DATE - OUTPUT RAE04560
         LA    9,PLORDQTY                                  - COUNT RAE04570
ZEROWA   ZAP   0(L'APLORDQTY,R8),PZERO  SET WORK AREA TO ZERO      RAE04580
         LA    8,L'APLORDQTY(R8)   INCREMENT WORK AREA             RAE04590
         BCT   5,ZEROWA            DECREMENT TOTAL TIME PERIODS    RAE04600
         CLI   MTMTSW,X'FF'        DOES NET OR OFFSET EXIST        RAE04605
         BNE   BALROUT             NO                              RAE04606
         LH    5,NUMTMPER          RESET TOTAL TIME PERIODS        RAE04610
         LA    8,PLORDQTY          RESET POINTER OF WORK AREA      RAE04620
LOOPPD   CP    0(L'AOSETQTY,7),=X'7000000C'  OFFSET P/O THIS TIME PERIOD RAE04630
         BE    BUMP                NO                              RAE04640
         CP    MLTME,=X'0000C'     LEAD TIME ZERO                  RAE04650
         BE    ZAPQTY              YES                             RAE04660
         LA    8,L'APLORDQTY(R8)   INCREMENT OUTPUT WORK AREA      RAE04670
         BCT   6,LOOPPD            DECREMENT LEAD TIME             RAE04680
ZAPQTY   AP    0(L'APLORDQTY,8),0(L'AOSETQTY,7)  OSETQTY TO DUE DATE RAE04690
         LA    7,L'AOSETQTY(R7)    INCREMENT OFFSET PLANNED ORDER  RAE04700
         LA    9,L'APLORDQTY(R9)   INCREMENT PLANNED ORDERS COUNT  RAE04710
         LR    8,9                 RESET POINTER OUTPUT WORK AREA  RAE04720
         CVB   6,HOLDLT            RESET LEAD TIME                 RAE04730
         BCT   5,LOOPPD            DECREMENT TOTAL TIME PERIODS    RAE04740
         B     BALROUT             WORK AREA EXHAUSTED             RAE04750
BUMP     LA    7,L'AOSETQTY(R7)    INCREMENT WORK AREAS            RAE04760
         LA    8,L'APLORDQTY(R8)                                   RAE04770
         LA    9,L'APLORDQTY(R9)                                   RAE04780
         BCT   5,LOOPPD            DECREMENT TOTAL TIME PERIODS    RAE04790
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE04800
* TO COMPUTE RUNNING ON HAND BALANCE. RAE04830 THRU RAE05270.      RAE04810
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RAE04820
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BALROUT  LH    5,NUMTMPER                     TOTAL TIME PERIODS                 RAE04830
         LA    6,BALWORK                      RUNNING ON HAND BALANCE            RAE04840
         LA    7,GROSSQTY                                                        RAE04900
         LA    8,PLORDQTY                                                        RAE04910
         LA    9,RELORDQ                                                         RAE04920
         CP    HOHTQ,=X'0000000C'             IS ON HAND A CREDIT                RAE04930
         BL    ZERObAL                        YES                                RAE04940
         CLI   MTYPW,C'3'                     RAW MATERIAL                       RAE04941
         BE    DECDROP                        YES                                RAE04942
         CLI   MTYPW,C'3'                     RAW MATERIAL                       RAE04943
         BNE   ADDOHH                         NO                                 RAE04944
DECDROP  ZAP   HOLDINV,HOHTQ                                                     RAE04945
         MVO   HOLDINV,HOLDINV(2)             DROP ONE DECIMAL PLACE             RAE04946
         ZAP   BALQTY,HOLDINV                 ON HAND INVENTORY                  RAE04947
         B     NOADD                                                             RAE04948
ADDOH    ZAP   BALQTY,HOHTQ                   ON HAND INVENTORY                  RAE04950
NOADD    SP    BALQTY,HOPSS                   SAFETY STOCK                       RAE04960
         SP    BALQTY,HALQT                   ALLOCATED STOCK                    RAE04970
LOOPRW   SP    BALQTY+0(L'GROSSQTY),7(0)      GROSS REQUIREMENTS                 RAE04980
         AP    BALQTY,0(L'PLORDQTY,8)         PLANNED ORDERS                     RAE04990
         AP    BALQTY,0(L'RELORDQ,9)          OPEN ORDERS                        RAE05000
         ZAP   0(L'BALWORK,6),BALQTY          TO WORK AREA                       RAE05005
         LA    6,L'BALWORK(6)                 INCREMENT WORK AREAS               RAE05010
         LA    7,L'GROSSQTY(7)                                                   RAE05020
         LA    8,L'PLORDQTY(8)                                                   RAE05030
         LA    9,L'RELORDQ(9)                                                    RAE05040
         BCT   5,LOOPRW                       DECREMENT TIME PERIODS             RAE05050
         L     5,RWSAVE5                      RESTORE REGISTERS                  RAE05060
         L     6,RWSAVE6                                                         RAE05070
         L     7,RWSAVE7                                                         RAE05080
         L     8,RWSAVE8                                                         RAE05090
         L     9,RWSAVE9                                                         RAE05100
BSDONE   L     11,=ACP1001                    ADDRESS OF PRINT ROUTINE           RAE05160
         LA    1,8                            CODE TO PRINT RUNNING O/H BAL      RAE05170
         BALR  14,11                                                             RAE05180
         B     RS1100                         END OF ROUTINE                     RAE05190
ZERObAL  ZAP   BALQTY,PZERO                   ZERO STARTING BALANCE ON HAND      RAE05195
         B     NOADD                                                             RAE05196
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *               RAE05200
* HOLD AREAS. RAE05210 THRU RAE05306.                                            RAE05210
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *               RAE05220
RWSAVE5  DS    F                                                                 RAE05230
RWSAVE6  DS    F                                                                 RAE05240
RWSAVE7  DS    F                                                                 RAE05250
RWSAVE8  DS    F                                                                 RAE05260
RWSAVE9  DS    F                                                                 RAE05270
HOLDLT   DS    0D                             DOUBLEWORD TO HOLD BINARY          RAE05290
         DC    PL8'0'                         CONVERSION OF LEAD TIME            RAE05300
BALQTY   DC    PL3'0'                         TO HOLD RUNNING ON HAND BAL.       RAE05305
HOLDINV  DC    PL3'0'                         HOLD INVENTORY W/DECIMAL PLACE     RAE05306
         MEND                                                                    RAE05310

         BKEND
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A.RPSCP V.M 0,0          106 BLOCKS          SYSTEM SOURCE-STATEMENT LIBRARY

         BKEND   A.RPSCP

         MACRO                                                                   RA000010
         RPSCP &NUMTMPR,&ITEMORM,&OPENORD,&NETREQT,&PLANORS,&OFFSETS,            RA000020
               &PRINTKL,&REQDLTN,&LINEDIT,&CEILT23                               RA000030
.*                                                                               RA000040
.*       RPSCP     COMMON PRINT ROUTINE             3404-MF-051   V1-L0          RA000050
.*--------------------------------------------------------------------           RA000060
.*                                                                               RA000070
.*                 THIS ROUTINE IS CALLED TO PRINT EITHER A DATA LINE OR         RA000080
.*       ONE OF SIX DETAIL LINES. TEN ENTRIES ARE PRINTED PER LINE.              RA000090
.*       THE TYPE OF LINE TO BE PRINTED IS PASSED IN REGISTER ONE BY             RA000100
.*       CALLING PHASE.                                                          RA000110
.*                                                                               RA000120
.*   REGISTER USAGE                                                              RA000130
.*                                                                               RA000140
.*               1     DETAIL LINE AND DATE LINE SELECTION CODE                  RA000150
.*               2     BASE FOR MAINLINE                                         RA000160
.*               3     BASE FOR COMMON AREAS                                     RA000170
.*               4     BASE FOR COMMON AREAS                                     RA000180
.*               5     WORK AREA MOVING POINTER                                  RA000190
.*               6     WORK REGISTER                                             RA000200
.*               7     DATE TABLE MOVING POINTER                                 RA000210
.*               8     PRINT AREA MOVING POINTER                                 RA000220
.*               9     PRINT COLUMN COUNTER                                      RA000230
.*              10     LAST DATE ENTRY POINTER                                   RA000240
.*              11     BASE REGISTER                                             RA000250
.*              14     CALLING ROUTINE RETURN ADDRESS                            RA000260
.*              15     SAVE AREA FOR IMMEDIATE CALCULATIONS                      RA000270
.*                                                                               RA000280
.*   LOCAL VARIABLE USAGE                                                        RA000290
.*                                                                               RA000300
.*               LCLA  &CAL1,&CAL2                                               RA000310
.*                                                                               RA000320
               LCLA  &CAL1,&CAL2                                                 RA000330
               USING CP1001,11                                                   RA000340
CP1001         ST    14,CPSAVE1           SAVE LINK ADDRESS                      RA000350
               ST    10,CPSAVE2           SAVE CALLING BASE REG                  RA000360
               CLC   CPITEMNO(L'&ITEMORM),&ITEMORM  IS THIS A NEW ITEM NUMBER    RA000370
               BNE   CP1001A                        YES, INITIALIZE              RA000380
               L     7,CPCALADR           NO,RESTORE CALENDAR ADDR               RA000390
               B     CP1002                         CONTINUE                     RA000400
CP1001A        MVC   CPITEMNO(L'&ITEMORM),&ITEMORM  SAVE NEW ITEM NUMBER         RA000410
               MVI   CPDISP,X'00'                                                RA000420
               MVC   CPDISP+1(L'CPDISP-1),CPDISP      CLEAR DISPLACEMENT         RA000430
               MVC   CPWADISP,CPDISP                  CLEAR WORK AREA DISPLACEMENT RA000440
               MVC   CPPNTR,CPDISP                    CLEAR DISPLACEMENT POINTER RA000450
               SR    5,5                        CLEAR W/A MOVING POINTER         RA000460
               SR    6,6                        CLEAR REG 6                      RA000470
&CAL1          SETA  &NUMTMPR                   NUMBER OF TIME PERIODS           RA000480
&CAL2          SETA  &CAL1*5-5                  DISPLACEMENT TO LAST TIME PERIOD RA000490
               AIF   ('&ITEMORM' EQ '&SHOP').CPA                                 RA000500
               LA    7,CALACT                   SET DATE POINTER FOR CALENDAR    RA000510
               LA    10,CALACT+&CAL2            OBTAIN LAST CALENDAR DATE        RA000520
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         AGO   .CPB                                                   RA000530
.CPA     LA    7,CALSHOP             SET DATE POINTER FOR SHOP        RA000540
         LA    10,CALSHOP+L'AL2      OBTAIN LAST SHOP DATE            RA000550
.CPB     ANOP                                                         RA000560
         ST    10,CPCALEND          LAST ADDR OF DATTABLE             RA000570
         LA    10,EAE(L'LAGROSSO)(7-LAGROSSOTT     W/A DISP           RA000580
         ST    10,CPWADISP          SAVE LAST W/A ADDR                RA000590
CP1002   LA    8,RPPRTIOA+9          RESET PRINTER POINTER            RA000600
         MVI   RPPRTIOA,C' '                                          RA000610
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA000617
* LENGTH ATTRIBUTE CHANGED FROM 131, RA000620.                        RA000618
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA000619
         MVC   RPPRTIOA+1(139),RPPRTIOA   CLEAR PRINT AREA            RA000620
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA000630
* TEST FOR ROUTINE TO PRINT RUNNING ON HAND BALANCE, RA000633 AND 634. RA000631
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA000632
         C     1,CPOSP8              REG 1 EQUAL TO EIGHT             RA000633
         BE    CP2001H               YES - GO TO RUNNING BALANCE      RA000634
         C     1,CPOSP1              REG ONE EQUAL ONE                RA000640
         BE    CP2001A               GO TO GROSS ROUTINE              RA000650
         AIF   T'&CPOPENORD EQ 'NO').CP10                             RA000660
         C     1,CPOSP2              REG ONE EQUAL TWO                RA000670
         BE    CP2001B               GO TO O/O ROUTINE                RA000680
.CP10    AIF   T'&CNET(C01) EQ 'NO').CP20                             RA000690
         C     1,CPOSP3              REG ONE EQUAL THREE              RA000700
         BE    CP2001C               GO TO NET ROUTINE                RA000710
.CP20    AIF   T'&CPLANORD EQ 'NONE').CP30                            RA000720
         C     1,CPOSP4              REG ONE EQUAL FOUR               RA000730
         BE    CP2001D               GO TO P/O ROUTINE                RA000740
.CP30    AIF   T'&COFFSET EQ 'NO').CP40                               RA000750
         C     1,CPOSP5              REG ONE EQUAL FIVE               RA000760
         BE    CP2001E               GOTO OFST ROUTINE                RA000770
.CP40    C     1,CPOSP6              REG ONE EQUAL SIX                RA000780
         BE    CP2001F               GO TO DATE ROUTINE               RA000790
         AIF   T'&CREQUALINE NE 'YES').CP50H                          RA000800
         C     1,CPOSP7              REG ONE EQUAL SEVEN              RA000810
         BE    CP2001G               GO TO A/O ROUTINE                RA000820
.CP50H   ANOP                                                         RA000830
* VALUE IN REGISTER ONE IS INCORRECT                                  RA000840
         MVC   ERRCODE,CPERR1        MOVE IN ERROR CODE               RA000850
         MVI   ERITEMNO,C' '         CLEAR ITEM NUMBER AREA           RA000860
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA000867
* LENGTH ATTRIBUTE CHANGED FROM 'ASMPN FOR UNPACKED KEY, RA000870.    RA000868
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA000869
         MVC   ERITEMNO+1(L'ERITEMNO-1),ERITEMNO                      RA000870
         LR    10,11                 SAVE BASE REGISTER               RA000880
         L     11,ATYPEOUT           LOAD ADDR OF ERROR ROUTINE       RA000890
         BALR  14,11                 BRANCH AND LINK TO ERROR ROUTINE RA000900
         LR    11,10                 RESTORE BASE REG                 RA000910
*                                                                     RA000920
         MVI   RPPRTIOA,C' '         CLEAR PRINT AREA                 RA000930
         MVC   RPPRTIOA+1(L'RPPRTIOA-1),RPPRTIOA                      RA000940
         B     CP1010                GO TO PRINT                      RA000950
*                                                                     RA000960
         AIF   T'&CEXIT23 EQ 'YES').CPT                               RA000970
CP1004   MVC   CPPGTOT,LINECNT        ADD LINE COUNT TO               RA000980
         AP    CPPGTOT,LINESET        LINESET, PLACE IN PAGE TOT      RA000990
         CP    CPPGTOT,LINPAGE             WILL THIS SET FIT ON PAGE  RA001000
         BH    CP1005                      NO, OVERFLOW               RA001010
         B     CP1006                                                 RA001020
CP1005   LR    10,11                       SAVE BASE REG              RA001030
         ST    1,CPINTCNT           SAVE INIT COUNT                   RA001040
         L     11,CPOFADDR                 LOAD ADDR OF OVERFLOW      RA001050
         BALR  14,11                       BRANCH TO OVERFLOW         RA001060
*                                                                     RA001070
         LR    11,10                       RESTORE BASE REG           RA001080
         L     1,CPINTCNT           LOAD INIT COUNT                   RA001090
.CPT     ANOP                                                         RA001100
CP1006   SR    9,9               CLEAR COLUMN COUNTER                 RA001110
         LA    9,1               PLACE A ONE IN COL COUNTER           RA001120
         AIF   T'&CITEMORMA EQ 'ASMCPRU).CPC                          RA001130
CP1001   APSOR CPDATE,CKTO              RECONVERT DATE                RA001140
         MVC   2510,25,CPPIANO   MOVE DATE PIRM TO PRINT              RA001150
         ED    2510,50,CPDATE EDIT DATE                               RA001160
         AGO   .CPD                                                   RA001170
.CPC     ANOP                                                         RA001180
CP1007   UNPK  413,80,0TZ,70            EDIT SHOP DATE                RA001190
         OI    11580,X'F0'                 STRIP ZONE                 RA001200
.CPD     ANOP                                                         RA001210
         C     7,CPCALEND        IS DATE POINTER AT END OF TABLE      RA001220
         BE    CP1008                                                 RA001230
         CH    9,CPLINE          IS PRINT AREA AT END                 RA001240
         BE    CP1009                                                 RA001250
         LA    7,5(7)            INCR DATE TABLE POINTER              RA001260
         LA    8,12(8)           INCR PRINT MOVING POINTER            RA001270
         LA    9,1(9)            INCR COLUMN COUNTER                  RA001280
         B     CP1007                                                 RA001290
CP1008   MVI   MLTENDSW,X'FF'    TURN ON MULTIPLE END SWITCH          RA001300
         B     CP1010                                                 RA001310
CP1009   LA    7,5(7)            INCR DATE TABLE POINTER              RA001320
         ST    7,CPCALADR           SAVE CAL POINTER                  RA001330
         AIF   T'&CEXIT23 EQ 'YES').CPW                               RA001340
*                                                                     RA001350
CP1010   PUT   RPPRINT           PRINT A LINE                         RA001360
*                                                                     RA001370
         AP    LINECNT,CPONE               ADD ONE TO LINE COUNT      RA001380
         AGO   .CPY                                                   RA001390
.CPW     ANOP                                                         RA001400
CP1010   LR    10,11             SAVE BASE REG                        RA001410
         L     11,AEXIT23        LOAD ADDR OF USER EXIT               RA001420
         BALR  14,11             BRANCH TO USER EXIT                  RA001430
*                                                                     RA001440
         LR    11,10             RESTORE BASE REG                     RA001450
.CPY     L     14,CPSAVE1                  RESTORE RETURN ADDR        RA001460
         L     10,CPSAVE2                  RESTORE CALLERS BASE REG   RA001470
         BR    14                          RETURN TO CALLER           RA001480
*                                                                     RA001490
*                                                                     RA001500
*        INITIALIZING ROUTINES                                        RA001510
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA001512
* RA001535-1536-1575-1576-1645-1646-1715-1716-1785-1786-1855-1856 SET RA001513
* ON THE APPROPRIATE SWITCH IF OPEN ORDERS OR OFFSET PLANNED ORDERS ARE RA001514
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* BEING PRINTED AND SET THEM OFF IF NOT. THIS IS TO ENABLE THE FLAGGING RA001515
* OF THESE QUANTITIES - * FOR OPEN ORDERS, * FOR OFFSET PLANNED ORDERS. RA001516
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA001517
CP2001A  LA    5,GROSSQTY                  SELECT GROSS QTY W/A         RA001520
         MVC   RPPRTIDATA+0,CPGROSS        MOVE AGROSS TO PRINT         RA001530
         MVI   SWOFSET,X'00'          NOT PRINTING OFFSET               RA001535
         MVI   SWOPEN,X'00'           NOT PRINTING OPEN ORDERS          RA001536
         B     CP2002                                                   RA001540
         AIF   ('&RCPENORDR' EQ 'NO').CPG                               RA001550
CP2001B  LA    5,RELORDQ                   SELECT RELEASED ORDERS W/A   RA001560
         MVC   RPPRTIDATA+0,CPOPEN         MOVE AOPENR TO PRINT         RA001570
         MVI   SWOFSET,X'00'          NOT PRINTING OFFSET               RA001575
         MVI   SWOPEN,X'FF'           PRINTING OPEN ORDERS              RA001576
         B     CP2002                                                   RA001580
         AGO   .CPH                                                     RA001590
.CPG     ANOP                                                           RA001600
* OPEN ORDERS NOT INCLUDED                                              RA001610
.CPH     AIF   ('&RCNETREQTR' EQ 'NO').CPJ                              RA001620
CP2001C  LA    5,NETQTY                    SELECT NET QTY W/A           RA001630
         MVC   RPPRTIDATA+0,CPNET          MOVE ANETR TO PRINT          RA001640
         MVI   SWOFSET,X'00'          NOT PRINTING OFFSET               RA001645
         MVI   SWOPEN,X'00'           NOT PRINTING OPEN ORDERS          RA001646
         B     CP2002                                                   RA001650
         AGO   .CPK                                                     RA001660
.CPJ     ANOP                                                           RA001670
* NET NOT INCLUDED                                                      RA001680
.CPK     AIF   ('&RCPLANORSR' EQ 'NONE').CPL                            RA001690
CP2001D  LA    5,PLORDQTY                  SELECT PLANNED ORDERS W/A    RA001700
         MVC   RPPRTIDATA+0,CPPLOR         MOVE APLORR TO PRINT         RA001710
         MVI   SWOFSET,X'00'          NOT PRINTING OFFSET               RA001715
         MVI   SWOPEN,X'00'           NOT PRINTING OPEN ORDERS          RA001716
         B     CP2002                                                   RA001720
         AGO   .CPM                                                     RA001730
.CPL     ANOP                                                           RA001740
* PLANNED ORDERS NOT INCLUDED                                           RA001750
.CPM     AIF   ('&RCOFFSETLR' EQ 'NO').CPP                              RA001760
CP2001E  LA    5,OSETQTY                   SELECT OFFSET QTY W/A        RA001770
         MVC   RPPRTIDATA+0,CPOFST         MOVE AOFSTR TO PRINT         RA001780
         MVI   SWOFSET,X'FF'          PRINTING OFFSET                   RA001785
         MVI   SWOPEN,X'00'           NOT PRINTING OPEN ORDERS          RA001786
         B     CP2002                                                   RA001790
         AGO   .CPRA                                                    RA001800
.CPP     ANOP                                                           RA001810
* OFFSET NOT INCLUDED                                                   RA001820
.CPRA    AIF   ('&RCREQALTNR' NE 'YES').CPRB                            RA001830
CP2001G  LA    5,NCPQQTY                  ADJUSTED ORDERS ARE FOUND HERE RA001840
         MVC   RPPRTIDATA+0,CPADJOR        MOVE AADJ ORDR TO PRINT      RA001850
         MVI   SWOFSET,X'00'          NOT PRINTING OFFSET               RA001855
         MVI   SWOPEN,X'00'           NOT PRINTING OPEN ORDERS          RA001856
         B     CP2002                                                   RA001860
         AGO   .CPR                                                     RA001870
.CPRB    ANOP                                                           RA001880
* ALCMNT ALTERATION NOT INCLUDED                                        RA001890
.CPR     AIF   ('&RCEDITZSR' EQ 'YES').CPS                              RA001900
CP2001F  CNTRL APPRINT,SP,1           SPACE ONE BEFORE PRINT SET        RA001910
         AP    LINECNT,CPRONE       ADD ONE TO LINE COUNT               RA001920
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         AGO   .CPVV                                                    RA001930
.CPS     ANOP                                                           RA001940
CP2001V  EQU   *                                                        RA001950
.CPVV    MVI   CPDSPSW,X'FF'               TURN ON DISPLACEMENT SW      RA001960
         MVC   CPDISP,CPPNTR               RESET DISPLACEMENT           RA001970
         AIF   ('&RCEDITZSR' EQ 'YES').CPN                              RA001980
         B     CP1004                                                   RA001990
         AGO   .CPY                                                     RA002000
.CPN     B     CP1006                                                   RA002010
.CPY     ANOP                                                           RA002020
*                                                                       RA002030
CP2002   SR    10,10                                                    RA002040
         L     10,CP-ADISP                                              RA002050
         AR    10,5          LAST WORK AREA ADDR                        RA002060
         A     5,CPDISP                ADD DISPLACEMENT TO W/A POINTER  RA002070
         SR    9,9                     CLEAR COLUMN COUNTER             RA002080
         LA    9,1                     PLACE A ONE IN COL COUNTER       RA002090
CP2003   ZAP   CPPACK,CSL(GROSSQTY+5)   QTY TO FOUR BYTE FIELD          RA002100
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA002104
* LENGTH ATTRIBUTE ON RA002110 AND 2120 CHANGED FROM 12 TO ACCOMODATE   RA002107
* PRINTING A FLAG FOR OPEN ORDERS AND OFFSET PLANNED ORDERS.            RA002108
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA002109
         MVC   2(10,8),CPPTRND           QTY PATTERN TO PRINT           RA002110
         ED    2(10,8),CPPACK            EDIT QTY IN PRINT AREA         RA002120
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA002121
* TEST SWITCHES FOR PRINTING OPEN ORDERS OR OFFSET PLANNED ORDERS. GO   RA002122
* TO PRINT FLAG ROUTINE IF ON. RA002125 THRU 2128.                      RA002123
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA002124
         CLI   SWOFSET,X'FF'             PRINTING OFFSET PLANNED ORDERS RA002125
         BE    TESTQTY               YES - TEST FOR ZERO OFFSET QTY     RA002126
         CLI   SWOPEN,X'FF'          PRINTING OPEN ORDERS               RA002127
         BE    TESTQTY               YES - TEST FOR ZERO OPEN ORDER QTY RA002128
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA002130
* TO TEST IF RUNNING ON HAND BALANCE IS A CREDIT AND IF SO TO PRINT     RA002131
* A CREDIT SYMBOL. RA002134 THRU RA002139.                              RA002132
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RA002133
         CLC   RPPRTIDATA+0,PCBALANCE    PRINTING RUNNING O/H BALANCE   RA002134
         BNE   TESTEND                   NO                             RA002135
         CP    CPPACK,=P'00000000C'      IS QTY A CREDIT                RA002136
         BNL   TESTEND                   NO                             RA002137
         MVC   12(1,8),=C'CR'            CREDIT SYMBOL TO PRINT         RA002138
TESTEND  CR    9,10                                                     RA002139
         BE    CP1010      YES, GO TO PRINT                             RA002140
         CH    9,CPLINE             IS PRINT AREA AT END                RA002150
         BE    CP2004               YES                                 RA002160
         LA    5,L'GROSSQTY(5)      INCR W/A MOVING POINTER             RA002170
         LA    8,12(8)              INCR PRINT POINTER                  RA002180
         LA    9,1(9)               INCR COLUMN COUNTER                 RA002190
         B     CP2003                                                   RA002200
CP2004   LA    5,L'GROSSQTY(5)      INCR W/A POINTER TO NEXT POSITION   RA002210
         CLI   CPDSPSW,X'FF'                                            RA002220
         BNE   CP1010                                                   RA002230
         MVI   CPDSPSW,X'00'                                            RA002240
         LA    6,GROSSQTY           OBTAIN START ADDR                   RA002250
         SR    5,6              OBTAIN DISPLACEMENT                     RA002260
         ST    5,CPPNTR             SAVE DISPLACEMENT                   RA002270
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         B     CP1010                                              RA002275
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002277
* PRINT APPROPRIATE FLAG IF FOR OPEN ORDERS,+ FOR OFFSET PLANNED ORDERS RA002278
* BLANK FLAG IF EITHER QUANTITY IS ZERO. RA002281 THRU 2290.         RA002279
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002280
TESTQTY  CLC   CPPACK,=X'000000000C'    ZERO QTY                   RA002281
         BE    NOFLAG                   YES                        RA002282
         CLI   $&OFSET,X'FF'            OFFSET QTY                 RA002283
         BE    PATAST                   YES - PRINT ASTERISK       RA002284
         MVC   [illegible]              OPEN ORDER FLAG            RA002285
         B     TESTEND                  RETURN TO MAINLINE         RA002286
PATAST   MVC   [illegible]              OFFSET - FLAG              RA002287
         B     TESTEND                  RETURN TO MAINLINE         RA002288
NOFLAG   MVC   [illegible]              BLANK FLAG                 RA002289
         B     TESTEND                  RETURN TO MAINLINE         RA002290
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002291
* TO PRINT RUNNING BALANCE ON HAND. RA002294 THRU 2298.            RA002292
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002293
CP2001H  LA    5,RNGWORK                RUNNING BALANCE WORK AREA  RA002294
         MVC   [illegible]BALANCE '     LINE TITLE TO PRINT        RA002295
         MVI   $&OFSET,X'00'            NOT PRINTING OFFSET        RA002296
         MVI   $&OPEN,X'00'             NOT PRINTING OPEN ORDERS   RA002297
         B     CP2002                                              RA002298
         DS    0F                                                  RA002300
CPCALEND DC    F'0'            LAST CAL ENTRY ADDR                 RA002310
CPCALADR DC    F'0'            CURRENT CAL ADDR                    RA002320
CPWADISP DC    F'0'            TOTAL BYTES OF WORK AREA            RA002330
CPDISP   DC    F'0'                                                RA002340
CPPWFR   DC    F'0'                                                RA002350
CPSAVE1  DC    F'0'                                                RA002360
CPSAVE2  DC    F'0'                                                RA002370
         AIF   ('&QTEMORD' EQ '&NOP').CPXX                         RA002380
CPDATE   DS    PL4                                                 RA002390
CPPTAND  DC    X'[illegible]'                                      RA002400
.CPXX    AIF   ('&EXIT23' EQ 'YES').CPF                            RA002410
CPOFADDR DC    A(OFF0014)                                          RA002420
CPINTCNT DC    F'0'                                                RA002430
CPPCTCT  DC    H'0'                                                RA002440
CPONE    DC    PL1'1'                                              RA002450
CPITEMNO DC    CL(&PARTNXL)' '              SAVED ITEM NUMBER      RA002460
         AGO   .CPE                                                RA002470
.CPF     ANOP                                                      RA002480
AEXIT23  DC    A(EXIT23)                                           RA002490
.CPE     ANOP                                                      RA002500
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002506
* VALUE CHANGED FROM 10 TIME PERIODS PER LINE TO ACCOMODATE 120    RA002507
* POSITION PRINTER. RA002510.                                      RA002508
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002509
CPLINE   DC    H'8'                                                RA002510
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002517
* VALUE CHANGED FROM 5 TO ACCOMODATE FLAG. RA002520.               RA002518
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002519
CPPACK   DC    PL4'0'                                              RA002520
CPOSPEN  DC    X'00'                                               RA002530
         AIF   ('&INVEDIT' EQ 'YES').CPINS1                        RA002540
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002543
* SIZE OF PATTERN CHANGED FROM 11 CHARACTERS TO ACCOMODATE FLAG.   RA002547
* RA002550 AND 2580.                                               RA002548
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002549
CPPIAND  DC    X'[illegible]'                                      RA002550
         AGO   .CPINS2                                             RA002560
.CPINS1  ANOP                                                      RA002570
CPPTAND  DC    X'[illegible]'                                      RA002580
.CPINS2  ANOP                                                      RA002590
CPREG1   DC    C'[illegible]'   INCORRECT VALUE IN REG ONE         RA002600
CPGROSS  DC    C'GROSS '                                           RA002610
         AIF   ('&QOPENORD' EQ 'NO').CP1                           RA002620
CPOPEN   DC    C'OPEN ORDS'                                        RA002630
.CP1     AIF   ('&NETREQ' EQ 'NO').CP2                             RA002640
CPNET    DC    C'NET  '                                            RA002650
.CP2     AIF   ('&PLANORD' EQ 'NONE').CP3                          RA002660
CPPLOR   DC    C'PLAN ORDS'                                        RA002670
.CP3     AIF   ('&OFFSETRQ' EQ 'NO').CP99                          RA002680
CPOFST   DC    C'OFFSET  '                                         RA002690
.CP99    AIF   ('&CREGALTN' NE 'YES').CP99M                        RA002700
CPADJOR  DC    C'LM ADJ ORDS'                                      RA002710
.CP99M   ANOP                                                      RA002720
CPOSP1   DC    F'0'                                                RA002730
         AIF   ('&OPENORD' EQ 'NO').CP50                           RA002740
CPOSP2   DC    F'0'                                                RA002750
.CP50    AIF   ('&NETREQ' EQ 'NO').CP52                            RA002760
CPOSP3   DC    F'0'                                                RA002770
.CP52    AIF   ('&PLANORD' EQ 'NONE').CP54                         RA002780
CPOSP4   DC    F'0'                                                RA002790
.CP54    AIF   ('&OFFSETRQ' EQ 'NO').CP56                          RA002800
CPOSP5   DC    F'0'                                                RA002810
.CP56    AIF   ('&CREGALTN' NE 'YES').CP56M                        RA002820
CPOSP7   DC    F'0'                                                RA002830
.CP56M   ANOP                                                      RA002840
CPOSP6   DC    F'0'                                                RA002850
CPOSP8   DC    F'0'                                                RA002851
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002852
* REFER TO RA001515 THRU 1556 AND 2124 THRU 2127 AND 2281 THRU 2291. RA002853
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  RA002854
$&OFSET  DC    X'00'          TO TEST IF OFFSET PLANNED ORDER      RA002855
$&OPEN   DC    X'00'          TO TEST IF OPEN ORDER                RA002856
         MEND                                                      RA002860

         @END
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A.RPACW  V.M 0.0        44 BLOCKS         SYSTEM SOURCE-STATEMENT LIBRARY

         RAEND   A.RPACW

         MACRO                                                         RAP00010
         RPACW &NETREQT,&PLANORS,&OFFSETH,&REQALTN,&OPENORD,&GROSSOT,&N-RAP00020
               UMTHPR,&QTYFDSZ,&GROSSNO,&OPENORD,&PLANORD,&INPUTNO,&CAR-RAP00030
               DFLD,&PARTNEL,&CONVPEN,&SMEXIST,&ADIBL                  RAP00040
*                                                                      RAP00050
*        RPACW     DATA AREAS COMMON TO PHASES 1,2,3 360A-MF-05X  MT-LO RAP00060
*----------------------------------------------------------------------RAP00070
*                                                                      RAP00080
*              GENERATE WORK AREAS COMMON TO OVERLAYS 1,2,3.           RAP00090
*        ALSO TABLE OF ADDRESS CONSTANTS REQUIRED TO HANDLE LINKAGE    RAP00100
*        BY THE SUBROUTINES TO THE I/O ROUTINES.                       RAP00110
*                                                                      RAP00120
*   REGISTER USAGE - NONE-GENERATES COMMON AREA.                       RAP00130
*                                                                      RAP00140
*      1. REQUIREMENTS GENERATION WORK AREAS                           RAP00150
*                                                                      RAP00160
GROSSQTY DS    &NUMTHPR.PL&QTYFDSZ      GROSS REQT WORK AREA           RAP00170
         AIF   ('&OPENORD' EQ 'NO').CM1                                RAP00180
RELORDQ  DS    &NUMTHPR.PL&QTYFDSZ      OPEN ORDERS WORKAREA           RAP00190
.CM1     AIF   ('&NETREQT' EQ 'NO').CM2                                RAP00200
NETQTY   DS    &NUMTHPR.PL&QTYFDSZ      NET REQT. WORK AREA            RAP00210
.CM2     AIF   ('&PLANORS' EQ 'NONE').CM3                              RAP00220
PLORDQTY DS    &NUMTHPR.PL&QTYFDSZ      PLAN ORDERS WORK AREA          RAP00230
.CM3     AIF   ('&OFFSETH' EQ 'NO').CM4                                RAP00240
OSETQTY  DS    &NUMTHPR.PL&QTYFDSZ      OFFSET WORK AREA               RAP00250
.CM4     ANOP                                                          RAP00260
COMGRQTY DS    &NUMTHPR.PL&QTYFDSZ      COMPONENT GROSS WORK AREA      RAP00270
         AIF   ('&REQALTN' EQ 'NO').CM5                                RAP00280
NCPOQTY  DS    &NUMTHPR.PL&QTYFDSZ      NET CHNG PLAN ORDERS WORK AREA RAP00290
.CM5     AIF   ('&NETREQT' EQ 'YES').CM6                               RAP00300
         AIF   ('&PLANORS' EQ 'NONE').CM6A                             RAP00310
.CM6     ANOP                                                          RAP00320
RPSWORK  DS    &NUMTHPR.PL&QTYFDSZ      RPS TIME SERIES WORK AREA      RAP00330
.CM6A    ANOP                                                          RAP00340
*                                                                      RAP00350
DACDFLDS DC    H'&CARDFLD' NUMBER OF DATE/QTY FIELDS PER CARD          RAP00360
WORKDQCT DC    H'&INPUTNO' NUMBER OF DATE/QTY FIELDS INPUT PER ITEM    RAP00370
         AIF   ('&GROSSOT' EQ 'NO').CM7                                RAP00380
GROSSNUM DC    H'&GROSSNO' NUMBER OF DATE/QTY FIELDS OF GROSS REQTS    RAP00390
         AGO   .CM8                                                    RAP00400
.CM7     ANOP                                                          RAP00410
GROSSNUM DC    H'&NUMTHPR' NUMBER OF  TIME PERIODS OF GROSS REQTS      RAP00420
.CM8     ANOP                                                          RAP00430
RELORNUM DC    H'&OPENORD' NUMBER OF  OPEN ORDER DATE/QTY FIELDS       RAP00440
PLANONUM DC    H'&PLANORD' NUMBER OF PLANNED ORDER DATE/QTY FIELDS     RAP00450
         AIF   ('&OFFSETH' EQ 'NO').CM9H                               RAP00460
OSPSTQTY DC    PL&QTYFDSZ'0'            REQMNTS OFFSET PAST 1ST PERIOD RAP00470
.CM9H    ANOP                                                          RAP00480
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RAP00490
* CREATE WORK AREA TO HOLD RUNNING ON HAND BALANCE. RAP00491.          RAP00491
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  RAP00492
BALWORK  DS    &NUMTHPR.PL&QTYFDSZ                                     RAP00493
*      2. SWITCHES AND CONSTANTS ETC                                   RAP00500
*                                                                      RAP00510
RPIOSVIO DC    F'0' SAVE REG10 STORAGE FOR I/O ROUTINES ON BOMP FILES  RAP00520
RPIOSAVR DS    18F                      B/P TO DIVISION REGS SAVE AREA. RAP00530
RPDACONV DS    D                        DATA CONVERSION WORK AREA      RAP00540
RENTRYSW DC    XL1'00'                  RE-ENTRY SWITCH                RAP00550
RPERRBSW DC    X'00'  WA PREFIX ERROR BYTES SWITCH.OFF=X'00',ON=X'FF'  RAP00560
RPERREWA DS    CL2    WA FOR ALL WA PREFIX ERROR BYTES                 RAP00570
RPCMPRAD DS    F      WA FOR COMPRESSED DISK ADDRESS FOR BM/P RECORDS  RAP00580
PZERO    DC    P'0'   ZERO PACKED FIELD                                RAP00590
MTEXPNAD DC    C'EXPNA'  P/I FOR EXPANDING ADDRS                       RAP00600
RPKEND   DC    C'ENDS'      END OF CHAIN MARKER                        RAP00610
MTOPEN   DC    C'OPENA'  P/I FOR OPENING BM/P FILES                    RAP00620
MTCLOSE  DC    C'CLOSA'                 P/I FOR CLOSING BM/P FILES     RAP00630
MTCOMPAD DC    C'CMPRA'                 P/I FOR COMPRESSING ADDRS      RAP00640
RPMRANPI DC    C'MRANA'                 P/I FOR RANDOM RETRIEVAL BY KEY RAP00650
RPMDIRPI DC    C'MDIRA'                 P/I FOR DIRECT RETR BY DISK ADDR RAP00660
RPMUPDPI DC    C'MUPDA'                 P/I FOR UPDATE OF RECORD ON DISK RAP00670
MTITEMSV DS    CL&PARTNEL               PARENT P/N SAVE AREA           RAP00680
MTMTSW   DC    X'00'                    MT SWITCH.                     RAP00690
MTPLBKT  DS    PL4                      PLAN ORDER WORK BUCKET. ALSO   RAP00700
*                                       REMAINING PLAN ORDER BUCKET.   RAP00710
MTREMRFO DS    PL4                      REMAINING REQUIREMENT BUCKET FOR RAP00720
*                                       PLAN ORDER SUBROUTINES.        RAP00730
*                                                                      RAP00740
.*   TEST FOR DUMMY SECTION                                            RAP00750
         AIF   ('&ADIBL' NE 'YES').CWAT5                               RAP00760
*                                                                      RAP00770
*   TABLE OF ADDRESS CONSTANTS - FOR LINKAGE TO I/O ROUTINES           RAP00780
*                                IN COMMON TO ALL PHASES.              RAP00790
*                                                                      RAP00800
RTYPEOUT DC    A(TYPEOUT)     CONSOLE ERROR MESSAGE ROUTINE            RAP00810
RPMRANK  DC    A(RPMRANKY)    READ I/M BY KEY                          RAP00820
RPMDIRA  DC    A(RPMDIRAD)    READ I/M BY D/A                          RAP00830
RPMUPDW  DC    A(RPMUPDWR)    WRITE I/M                                RAP00840
RPMCALL  DC    A(RPMCAL10)    CALL BOMP IO DIV RCALLL MACRO FOR I/M    RAP00850
RPPSTGE  DC    A(RPPSTGET)    READ P/S                                 RAP00860
RPPCALL  DC    A(RPPCAL10)    CALL BOMP IO DIV RCALLL MACRO FOR P/S    RAP00870
RPMSEQR  DC    A(RPMSFORW)    READ SEQ. I/M                            RAP00880
RPMSEQU  DC    A(RPMSEQUP)    WRITE SEQ. I/M                           RAP00890
RPMERBT  DC    A(RPMERBYT)    TEST I/M WA ERROR BYTES ROUTINE          RAP00900
RPIDERM  DC    A(RPIDERMS)    BOMP IO ERROR MESSAGE ROUTINE            RAP00910
ADFEOEXO DC    A(DFEOEXOP)    OPEN DISK EXCEPTION NOTICE FILE          RAP00920
ADFEOEXW DC    A(DFEOEXWR)    WRITE DISK EXCEPTION NOTICE FILE         RAP00930
ADFEOEXC DC    A(DFEOEXCL)    CLOSE DISK EXCEPTION NOTICE FILE         RAP00940
.*   TEST IF S/M FILE EXISTS                                           RAP00950
         AIF   ('&SMEXIST' NE 'YES').CWAT1                             RAP00960
RPRCALL  DC    A(RPRCAL10)    CALL BOMP IO DIV RCALLL MACRO FOR S/M    RAP00970
RPRSEQR  DC    A(RPRSFORW)    READ SEQ. S/M                            RAP00980
RPRSEQU  DC    A(RPRSEQUP)    WRITE SEQ. S/M                           RAP00990
RPRERBT  DC    A(RPRERBYT)    TEST S/M WA ERROR BYTES ROUTINE          RAP01000
.CWAT1   ANOP                                                          RAP01010
.*   TEST FOR CONVERSATIONAL PLANNING LOGIC USED                       RAP01020
         AIF   ('&CONVPEN' NE 'YES').CWAT2                             RAP01030
ADFIDLTW DC    A(DFIDLTWR)    OPEN, WRITE, CLOSE ISTORE=LEVEL TABLE FILE RAP01040
ADFEILTR DC    A(DFEILTRD)    OPEN, LOAD, CLOSE ILOAD= LEVEL TABLE FILE RAP01050
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.CHAT2    ANOP                                                           RAPO1000
          AGO   .CHAT9                                                   RAPO1020
.CHAT5    ANOP                                                           RAPO1080
*                                                                        RAPO1090
*  DUMMY SECTION FOR ADDRESS TABLE IN STORAGE - FOR LINKAGE TO COMMON    RAPO1100
*                                               I/O ROUTINES.            RAPO1110
*                                                                        RAPO1120
ATYPEOUT DS     F                   CONSOLE ERROR MESSAGE ROUTINE        RAPO1130
ARPNRANK DS     F                   READ I/M BY KEY                      RAPO1140
ARPNDIRA DS     F                   READ I/M BY D/A                      RAPO1150
ARPNUPDW DS     F                   WRITE I/M                            RAPO1160
ARPNCALT DS     F                   CALL ROMP TO DIV SCALLL MACRON FOR I/M RAPO1170
ARPPSIGE DS     F                   READ P/S                             RAPO1180
ARPPCALT DS     F                   CALL ROMP TO DIV SCALLL MACRON FOR P/S RAPO1190
ARPNSEQR DS     F                   READ SEQ. I/M                        RAPO1200
ARPNSEQU DS     F                   WRITE SEQ. I/M                       RAPO1210
ARPMERRY DS     F                   TEST I/M WA ERROR BYTES ROUTINE      RAPO1220
ARPIOERM DS     F                   ROMP IO ERROR MESSAGE ROUTINE        RAPO1230
ADFEOEFO DS     F                   OPEN DISK EXCEPTION NOTICE FILE      RAPO1240
ADFENEXW DS     F                   WRITE DISK EXCEPTION NOTICE FILE     RAPO1250
ADFENERC DS     F                   CLOSE DISK EXCEPTION NOTICE FILE     RAPO1260
.*  TEST IF S/M FILE EXISTS                                              RAPO1270
          AIF   (&CSMEXIST@ NE &Y@@).CHAT6                               RAPO1280
ARPRCALT DS     F                   CALL ROMP TO DIV SCALLL MACRON FOR S/M RAPO1290
ARPRSEQR DS     F                   READ SEQ. S/M                        RAPO1300
ARPRSEQU DS     F                   WRITE SEQ. S/M                       RAPO1310
ARPRERRY DS     F                   TEST S/M WA ERROR BYTES ROUTINE      RAPO1320
.CHAT6    ANOP                                                           RAPO1330
.*  TEST FOR CONVERSATIONAL PLANNING LOGIC USED                          RAPO1340
          AIF   (&CCONVPLN@ NE &YES@@).CHAT7                             RAPO1350
ADFEOLTM DS     F                   OPEN, WRITE, CLOSE STORAGE LEVEL TABLE FILE RAPO1360
ADFEILTM DS     F                   OPEN, LOAD, CLOSE STORAGE LEVEL TABLE FILE  RAPO1370
.CHAT7    ANOP                                                           RAPO1380
.CHAT9    ANOP                                                           RAPO1390
          MEND                                                           RAPO1400

       BKEND
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A.RPSIR  V-M 0.0          159 BLOCKS           SYSTEM SOURCE-STATEMENT LIBRARY

              BKEND   A.RPSIR

                 MACRO                                                    RBG00010
                 RPSIR  &INPUTGR,&INPUTIR,&CONVPLN,&GROSSRT,&GROSSOT,&GROSSNO,&N RBG00020
                       UNTNPR,&NETREQT,&PLANORD,&PLANOND,&PLANORS,&OPENORD,&OFF RBG00030
                       SETR,&ATOALTN,&PRNTSEQ,&EXITOT,&EXIT12             RBG00040
          *                                                               RBG00050
          *      RPSIR     INITIALIZE THIS RUN               3606-MF-051  VI-LO RBG00060
          *      ---------------------------------------------------------- RBG00070
          *             THIS SUBROUTINE TESTS ALL RUN PARAMETERS FOR VALIDITY, RBG00080
          *      AND ESTABLISHES THE NUMBER OF SPACES REQUIRED TO PRINT ONE RBG00090
          *      SET OF DATA - WHICH IS USED FOR SPACE CONTROL IN PRINTING. RBG00100
          *                                                               RBG00110
          *   REGISTER USAGE                                              RBG00120
          *                                                               RBG00130
          *      1      SAVE FOR BASE                                     RBG00140
          *      2      BASE FOR MAINLINE                                 RBG00150
          *      3      BASE FOR COMMON AREAS                             RBG00160
          *      4      BASE FOR COMMON AREAS                             RBG00170
          *      5      ADDRESS WORK AREA IQUANTITY                       RBG00180
          *      6      WORK REGISTER-/NUMBER TIME PERIOD EQUAL USAGE     RBG00190
          *      9      INTERNAL SUBROUTINE LINKAGE                       RBG00200
          *      10     SAVE BASE REGISTER FOR INTERNAL LINKAGE           RBG00210
          *      11     BASE REGISTER                                     RBG00220
          *      14     CALLING ROUTINE RETURN ADDRES                     RBG00230
          *                                                               RBG00240
                 USING  IRI001,11                                         RBG00250
          IRI001 ST     14,IRSAVE14                                       RBG00260
                 LR     10,15                                             RBG00270
          * TURN ON VALIDITY SWITCHES FROM CUSTOMIZING TESTS              RBG00280
          *                                                               RBG00290
                 AIF    (&CREQALTN@ NE &YES@@).S01                        RBG00300
                 AIF    (&CPLANORD@ EQ &NO@@).S01                         RBG00310
                 MVI    TSTRQAL,X'FF'        INCLUDE REQUIREMENT ALTERATION RBG00320
          .S01   AIF    (&CNETREQT@ NE &YES@@).S02                        RBG00330
                 MVI    TSTNTRD,X'FF'        INCLUDE NET                  RBG00340
          .S02   AIF    (&CPLANORS@ EQ &NONE@@).S03                       RBG00350
                 MVI    TSTPLOR,X'FF'        INCLUDE PLANNED ORDERS       RBG00360
          .S03   AIF    (&CPLANORS@ EQ &NONE@@).S04                       RBG00370
                 AIF    (&CPLANORD@ EQ &NO@@).S04                         RBG00380
                 MVI    TSTSTPO,X'FF'        INCLUDE P/O AND STORE P/O    RBG00390
          .S04   AIF    (&COFFSETR@ NE &YES@@).S05                        RBG00400
                 MVI    TSTOFST,X'FF'        INCLUDE OFFSET               RBG00410
          .S05   AIF    (&CPLANORD@ EQ &NO@@).S07                         RBG00420
                 AIF    (&CCONVPLN@ NE &YES@@).S07                        RBG00430
                 MVI    TSTENTY,X'FF'        INCLUDE P/O FOR CONV PLANNING RBG00440
                 AIF    (&COFFSETR@ NE &YES@@).S07                        RBG00450
                 MVI    TSTOATY,X'FF'        INCLUDE O/S FOR STORED P/O   RBG00460
          .S07   AIF    (&CPRNTSEQ@ NE &YES@@).S09                        RBG00470
                 MVI    TSTPSEQ,X'FF'        INCLUDE PRINT SEQ            RBG00480
                 AIF    (&CCONVPLN@ NE &YES@@).S09                        RBG00490
                 MVI    TSTPCNV,X'FF'        INCLUDE PRT SEQ FOR INTRPT   RBG00500
          .S09   AIF    (&COPENORD@ EQ &NO@@).S10                         RBG00510
                 MVI    TSTOOOR,X'FF'        INCLUDE OPEN ORDERS          RBG00520
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+510     ANOP                                                            RBG00530
IR1015   CLC   PARNETCG,IRCHAR1         TEST FOR REQUIREMENTS ALTERATION RBG00540
         BNE   IR1016                   IF NOT REQ ALT, BRANCH.          RBG00550
         MVI   ASWITCH,X'FF'            REQ ALT RUN, TURN ON A SWITCH    RBG00560
         B     IR1017                                                    RBG00570
IR1016   CLC   PARNETCG,IRBLANK         TEST FOR NO REQ. ALTERATION      RBG00580
         BE    IR1017                                                    RBG00590
         MVC   ERRCODE,IRER05           INVALID REQ ALT. PARAMETER CODE. RBG00600
         BAL   9,IR1059                 BRANCH TO COMMON ERROR HANDLING  RBG00610
IR1017   CLC   PARINTER,IRCHAR1         TEST FOR AN INTERRUPT RUN.       RBG00620
         BNE   IR1018                                                    RBG00630
         CLC   PARPLAN,IRCHAR1          IS INT. TEST FOR STORE PLAN ORD. RBG00640
         BE    IR1019                                                    RBG00650
         MVC   ERRCODE,IRER06           INVALID INTERRUPT OR PLAN ORDER  RBG00660
         BAL   9,IR1059                                                  RBG00670
         B     IR1019                                                    RBG00680
IR1018   CLC   PARINTER,IRBLANK         TEST FOR NO INTERRUPT THIS RUN.  RBG00690
         BE    IR1019                                                    RBG00700
         MVC   ERRCODE,IRER07           INVALID INTERRUPT PARAMETER CODE RBG00710
         BAL   9,IR1059                                                  RBG00720
IR1019   CLC   PARRENTY,IRBLANK         TEST FOR NO REENTRY THIS RUN     RBG00730
         BE    IR1021                   TAKE BRANCH IF NO REENTRY.       RBG00740
         CLC   PARRENTY,IRCHAR1         TEST FOR REENTRY NO OFFSET       RBG00750
         BE    IR1020                   IF YES TAKE BRANCH               RBG00760
         CLC   PARRENTY,IRCHAR2         TEST FOR REENTRY OFF SET REENTRY RBG00770
         BE    IR1020                                                    RBG00780
         CLC   PARRENTY,IRCHAR3         TEST FOR RE-ENTRY ALREADY OFFSET RBG00790
         BE    IR1020                   IF YES BRANCH                    RBG00800
         MVC   ERRCODE,IRER08           INVALID RE-ENTRY PARAMETER       RBG00810
         BAL   9,IR1059                                                  RBG00820
IR1020   MVI   ASWITCH,X'FF'            REENTRY RUN TURN ON A SWITCH.    RBG00830
IR1021   CLC   PARPHASE,IRCHAR1         TEST FOR PHASE ONE ONLY.         RBG00840
         BE    IR1022                   IF YES TAKE BRANCH               RBG00850
         CLC   PARPHASE,IRBLANK         TEST FOR PHASE ONE AND TWO.      RBG00860
         BE    IR1022                                                    RBG00870
         MVC   ERRCODE,IRER09           INVALID PHASE PARAMETER          RBG00880
         BAL   9,IR1059                                                  RBG00890
IR1022   CLC   PARGROSS,IRCHAR1         TEST FOR GROSS ONLY.             RBG00900
         BE    IR1023                   IF YES TAKE BRANCH.              RBG00910
         CLC   PARGROSS,IRBLANK         TEST FOR GROSS THIS RUN.         RBG00920
         BE    IR1023                                                    RBG00930
         MVC   ERRCODE,IRER10           INVALID GROSS PARAMETER          RBG00940
         BAL   9,IR1059                                                  RBG00950
IR1023   CLC   PARNET,IRCHAR1           TEST FOR NET THIS RUN.           RBG00960
         BE    IR1025                   IF YES TAKE BRANCH.              RBG00970
         CLC   PARNET,IRBLANK           TEST FOR NO NET THIS RUN.        RBG00980
         BE    IR1025                                                    RBG00990
         MVC   ERRCODE,IRER12           INVALID NET PARAMETER            RBG01000
         BAL   9,IR1059                                                  RBG01010
         B     IR1025                                                    RBG01020
IR1024   CLC   PARGROSS,IRCHAR1                                          RBG01030
         BNE   IR1025                                                    RBG01040
         MVC   ERRCODE,IRER11           INVALID GROSS OR NET PARAMETER   RBG01050
         BAL   9,IR1059                                                  RBG01060
IR1025   CLC   PARPLAN,IRCHAR1          TEST FOR PLAN ORDERS AND STORE.  RBG01070
         BNE   IR1026                   IF NOT CODE 1 TAKE BRANCH.       RBG01080
         CLC   PARGROSS,IRCHAR1         TEST FOR GROSS AND PLAN ORD.     RBG01090
         BNE   IR1028                                                    RBG01100
         MVC   ERRCODE,IRER13           INVALID GROSS OR PLAN ORD. PARAM RBG01110
         BAL   9,IR1059                                                  RBG01120
         B     IR1028                   IF PARGROSS BLANK TAKE BRANCH.   RBG01130
IR1026   CLC   PARPLAN,IRBLANK          TEST FOR NO PLAN ORD.            RBG01140
         BE    IR1027                   TAKE BRANCH IF BLANK.            RBG01150
         CLC   PARPLAN,IRCHAR2          TEST FOR PLAN ORDER NO STORE.    RBG01160
         BNE   IR1027                                                    RBG01170
         MVC   ERRCODE,IRER14           INVALID PLAN ORDER PARAMETER     RBG01180
         BAL   9,IR1059                                                  RBG01190
IR1027   CLI   ASWITCH,X'FF'            TEST IF ASWITCH IS ON            RBG01200
         BNE   IR1028                   IF NOT ON TAKE BRANCH            RBG01210
         MVC   ERRCODE,IRER15           INVALID REQ ALT. OR REENTRY OR   RBG01220
         BAL   9,IR1059                 PLAN ORDER PARAMETER             RBG01230
IR1028   CLC   PAROFFST,IRCHAR1         TEST IF OFFSET THIS RUN          RBG01240
         BNE   IR1029                   IF NO TAKE BRANCH.               RBG01250
         CLC   PARGROSS,IRCHAR1         TEST IF GROSS ONLY               RBG01260
         BNE   IR1030                                                    RBG01270
         MVC   ERRCODE,IRER16           INVALID GROSS OR OFFSET PARAM    RBG01280
         BAL   9,IR1059                                                  RBG01290
         B     IR1030                   GROSS PARAM OK TAKE BRANCH.      RBG01300
IR1029   CLC   PAROFFST,IRBLANK         TEST FOR NO OFFSET THIS RUN.     RBG01310
         BE    IR1030                                                    RBG01320
         MVC   ERRCODE,IRER17           INVALID OFFSET PARAMETER         RBG01330
         BAL   9,IR1059                                                  RBG01340
IR1030   CLC   PARPRINT,IRBLANK         TEST FOR PRINT AS PROCESS.       RBG01350
         BE    IR1030A                  IF YES TAKE BRANCH.              RBG01360
         CLC   PARPRINT,IRCHAR1         TEST FOR PRINT SEQ.ACTIVE ONLY.  RBG01370
         BE    IR1030A                  IF YES TAKE BRANCH.              RBG01380
         CLC   PARPRINT,IRCHAR2         TEST FOR PRINT SEQ TOTAL FILE.   RBG01390
         BE    IR1030A                                                   RBG01400
         MVC   ERRCODE,IRER18           INVALID PRINT PARAMETER          RBG01410
         BAL   9,IR1059                                                  RBG01420
IR1030A  B     IR1030B                  GO TEST REST OF PRINT PARAMETER  RBG01430
*                                                                        RBG01440
*  TEST VALIDITY OF RUN PARAMETERS                                       RBG01450
*                                                                        RBG01460
IR1032   CLI   PARNETCG,C'1'            IS THIS A REQ. ALT. RUN.         RBG01470
         BNE   MOA                      NO, CONTINUE                     RBG01480
         CLI   ISTROAL,X'FF'            IS REQUIREMENTS ALTN REQUESTED   RBG01490
         BE    MOA                      YES, CONTINUE                    RBG01500
         MVC   ERRCODE,MOERR01          NO, LOAD ERROR CODE              RBG01510
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR             RBG01520
*                                                                        RBG01530
MOA      CLI   PARNET,C'1'              IS NET TO BE PERFORMED           RBG01540
         BNE   MOB                      NO, CONTINUE                     RBG01550
         CLI   ISTNIAO,X'FF'            IS NET REQUESTED                 RBG01560
         BE    MOB                      YES, CONTINUE                    RBG01570
         MVC   ERRCODE,MOERR02          NO, LOAD ERROR CODE              RBG01580
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR             RBG01590
*                                                                        RBG01600
MOB      CLI   PARPLAN,C'1'             IS P/O TO BE PERFORMED           RBG01610
         BNE   MOC                      NO, CONTINUE                     RBG01620
         CLI   ISTPLOR,X'FF'            IS P/O REQUESTED                 RBG01630
         BE    MOC                      YES, CONTINUE                    RBG01640
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         MVC   ERRCODE,MOERR03          NO, LOAD ERROR CODE                RBG01650
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR               RBG01660
*                                                                          RBG01670
MOC      CLI   PARPLAN,C'1'             IS P/O TO BE STORED                RBG01680
         BNE   MOD                      NO, CONTINUE                       RBG01690
         CLI   TSTSTPO,X'FF'            IS STORE P/O REQUESTED             RBG01700
         BE    MOD                      YES, CONT                          RBG01710
         MVC   ERRCODE,MOERR04          NO, LOAD ERROR CODE                RBG01720
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR               RBG01730
*                                                                          RBG01740
MOD      CLI   PAROFFST,C'1'            IS OFFSET TO BE PERFORMED          RBG01750
         BNE   MOE                      NO, CONTINUE                       RBG01760
         CLI   TSTOFST,X'FF'            IS OFFSET REQUESTED                RBG01770
         BE    MOE                      YES, CONT                          RBG01780
         MVC   ERRCODE,MOERR05          NO, LOAD ERROR CODE                RBG01790
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR               RBG01800
*                                                                          RBG01810
MOE      CLI   PARINTLK,C'1'            IS INTERRUPT TO BE PERFORMED       RBG01820
         BNE   MOF                      NO, CONTINUE                       RBG01830
         CLI   TSTRNTY,X'FF'            IS INTERRUPT REQUESTED             RBG01840
         BE    MOF                      YES, CONTINUE                      RBG01850
         MVC   ERRCODE,MOERR06          NO, LOAD ERROR CODE                RBG01860
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR               RBG01870
*                                                                          RBG01880
MOF      CLI   PARRENTY,C'1'            IS P/O, NO O/S, TO BE PERFORMED    RBG01890
         BE    MOG                      YES, CONTINUE                      RBG01900
         CLI   PARRENTY,C'3'            IS P/O ALREADY OFFSET              RBG01910
         BNE   MOH                      NO, CONTINUE                       RBG01920
MOG      CLI   TSTRNTY,X'FF'            WAS P/O STORED FOR CONV PLNG       RBG01930
         BE    MOJ                      YES, CONTINUE                      RBG01940
         MVC   ERRCODE,MOERR07          NO, LOAD ERROR CODE                RBG01950
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR               RBG01960
         B     MOJ                                                         RBG01970
MOH      CLI   PARRENTY,C'2'            IS P/O WITH O/S TO BE PERFORMED    RBG01980
         BNE   MOJ                      NO, CONTINUE                       RBG01990
         CLI   TSTONTY,X'FF'            WAS REENTRY REQUESTED              RBG02000
         BE    MOJ                      YES, CONTINUE                      RBG02010
         MVC   ERRCODE,MOERR08          NO, LOAD ERROR CODE                RBG02020
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR               RBG02030
*                                                                          RBG02040
MOJ      CLI   PARPRINT,C'1'            PRT SEQ ACTIVE ITEMS TO BE DONE    RBG02050
         BE    MOK                      YES, CONTINUE                      RBG02060
         CLI   PARPRINT,C'2'            PRT SEQ ITEMS IN I/M TO BE DONE    RBG02070
         BNE   MOL                      NO, CONTINUE                       RBG02080
MOK      CLI   TSTPSEQ,X'FF'            PRINT SEQ REQUESTED                RBG02090
         BE    MOL                      YES, CONTINUE                      RBG02100
         MVC   ERRCODE,MOERR09          NO, LOAD ERROR CODE                RBG02110
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR               RBG02120
*                                                                          RBG02130
MOL      CLI   PARPARAC,C'1'            PRT SEQ CURR ITEMS TO BE DONE      RBG02140
         BNE   MON                      NO, CONTINUE                       RBG02150
         CLI   TSTPCNV,X'FF'            PRT SEQ PREV INPRTS REQUESTED      RBG02160
         BE    MON                      YES, CONTINUE                      RBG02170
         MVC   ERRCODE,MOERR10          NO, LOAD ERROR CODE                RBG02180
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR               RBG02190
*                                                                          RBG02200
MON      CLI   PARPARAC,C'2'            IGNORE PRINTING PREV INTRPTS       RBG02210
         BE    MOW                      YES, CONTINUE                      RBG02220
         CLI   TSTPCNV,X'FF'            PRT SEQ PREV INTRPTS REQUESTED     RBG02230
         BE    MOW                      YES, CONTINUE                      RBG02240
         MVC   ERRCODE,MOERR11          NO, LOAD ERROR CODE                RBG02250
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR               RBG02260
*                                                                          RBG02270
MOW      CLI   PRIOPORD,C'1'            PRINT O/O TO BE PERFORMED          RBG02280
         BNE   MOP                      NO, CONTINUE                       RBG02290
         CLI   TSTPOSR,X'FF'            PRINT O/O REQUESTED                RBG02300
         BE    MOP                      YES, CONTINUE                      RBG02310
         MVC   ERRCODE,MOERR12          NO, LOAD ERROR CODE                RBG02320
         BAL   9,MOPRERR                BRANCH TO TYPE ERROR               RBG02330
*                                                                          RBG02340
MOP      CLI   MOERRSW,X'FF'            TEST FOR RUN PARAMETER ERRORS      RBG02350
         BNE   IR1031                   NO ERRORS, CONTINUE                RBG02360
         L     11,ABNRABND              YES, GO TO ABNORMAL EOJ            RBG02370
         BR    11                                                          RBG02380
*                                                                          RBG02390
IR1031   PACK  PARNUM,PARNUM            PACK NUM SHOP DAYS PER TIME PER.   RBG02400
*****FOLLOWING CODE CALCULATES NUMBER OF LINES TO BE PRINTED PER SET***    RBG02410
         CLC   PATIND,INCHAR1           IF USER HAS NOT SPECIFIED PRINT    RBG02420
*                                       INDICATIVE,IS ASSUMED NO PRINT     RBG02430
         BNE   IR1031F                                                     RBG02440
         AP    LINESET,INPACK1          ADD ONE FOR DATE HEADING.          RBG02450
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RBG02451
* ADD ONE TO LINE COUNT TO PRINT RUNNING ON HAND BALANCE. RBG02454.         RBG02452
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *    RBG02453
         AP    LINESET,INPACK1                                             RBG02454
         CLC   PRTGROSS,INCHAR1         TEST IF PRINT GROSS.               RBG02460
         BNE   IR1031A                  NO PRINT, BRANCH TO NEXT TEST.     RBG02470
         AP    LINESET,INPACK1          ADD ONE FOR PRINT GROSS.           RBG02480
IR1031A  CLC   PRIOPORD,INCHAR1         TEST IF PRINT OPEN ORDERS.         RBG02490
         BNE   IR1031B                  NO PRINT, BRANCH TO NEXT TEST.     RBG02500
         AP    LINESET,INPACK1          ADD ONE FOR PRINT OPEN ORDERS.     RBG02510
IR1031B  CLC   PRTNET,INCHAR1           TEST IF PRINT NET.                 RBG02520
         BNE   IR1031C                  NO PRINT, BRANCH TO NEXT TEST.     RBG02530
         AP    LINESET,INPACK1          ADD ONE FOR PRINT NET.             RBG02540
IR1031C  CLC   PRTPLORD,INCHAR1         TEST IF PRINT PLAN ORDERS.         RBG02550
         BNE   IR1031D                  NO PRINT, BRANCH TO NEXT TEST.     RBG02560
         AP    LINESET,INPACK1          ADD ONE FOR PRINT PLAN ORDERS.     RBG02570
IR1031D  CLC   PRINFSET,INCHAR1         TEST IF PRINT OFFSET.              RBG02580
         BNE   IR1031E                  NO PRINT, BRANCH TO LAST ADD       RBG02590
         AP    LINESET,INPACK1          ADD ONE FOR PRINT OFFSET           RBG02600
IR1031E  AP    LINESET,INPACK1          ADD ONE FOR SPACE AFTER SET        RBG02610
IR1031F  B     IR1060                   CONTINUE INITIALIZATION.           RBG02620
MLTEMP   DS    F                        SAVE AREAS FOR REGISTERS USED      RBG02630
MLSAVE5  DS    F                        IN THIS PORTION OF MAINLINE        RBG02640
MLSAVE6  DS    F                        ROUTINE.                           RBG02650
MLSAVE7  DS    F                                                           RBG02660
IRSAVE14 DS    F                                                           RBG02670
************************************************************************   RBG02680
* FOLLOWING IS COMMON EXIT AND ENTRY TO THE TYPE ERROR MESSAGE ROUTINE*    RBG02690
************************************************************************   RBG02700
IR1059   MVC   ERITEMNO,PARTBLK         MOVE BLANKS TO ERROR PART NUMBER   RBG02710
         MVI   MOERRSW,X'FF'            TURN ON VALIDITY ERROR SWITCH      RBG02720
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         LR    10,11              SAVE BASE REGISTER FOR RETURN       RRG02730
         L     11,ATYPEOUT        ADDRESS OF TYPE ERROR               RRG02740
         BALR  14,11                                                  RRG02750
         LR    11,10              RETURN FROM ERROR MESSAGE           RRG02760
         BR    9                  RETURN TO PARAM VALIDITY TESTS      RRG02770
NOPRERR  EQU   IR1059                                                 RRG02780
***********************************************************************RRG02790
* FOLLOWING CODE TESTS THE PRINT PARAMETERS.                        * RRG02800
***********************************************************************RRG02810
IR1030B  CLC   PARPRRAC,IRBLANK   TEST PRINT ALL ITEM RUN NUMBER      RRG02820
         BE    IR1030C            EQUAL. DO NOT PRINT ALL BRANCH.     RRG02830
         CLC   PARPRRAC,IRCHAR1                                       RRG02840
         BE    IR1030C            DO PRINT ALL EQUAL RUN NUMBER.      RRG02850
         MVC   ERRCODE,IRER24     PRINT ALL ITEMS WITH SAME RUN       RRG02860
         BAL   9,IR1059           NUMBER PARAMETER WRONG              RRG02870
IR1030C  CLC   PRTIND,IRBLANK     TEST PRT INDICATIVE PARAMETER.      RRG02880
         BE    IR1030D            DO NOT PRT INDICATIVE.              RRG02890
         CLC   PRTIND,IRCHAR1     TEST PRT INDIC. ON                  RRG02900
         BE    IR1030D                                                RRG02910
         MVC   ERRCODE,IRER25     PRT INDICATIVE PARAMETER WRONG.     RRG02920
         BAL   9,IR1059                                               RRG02930
IR1030D  CLC   PRTGROSS,IRBLANK   TEST PRT GROSS PARAMETER            RRG02940
         BE    IR1030E            DO NOT PRINT GROSS                  RRG02950
         CLC   PRTGROSS,IRCHAR1                                       RRG02960
         BE    IR1030E            DO PRINT GROSS                      RRG02970
         MVC   ERRCODE,IRER26     PRT GROSS PARAM. WRONG.             RRG02980
         BAL   9,IR1059                                               RRG02990
IR1030E  CLC   PRTOPORD,IRBLANK   TEST PRINT OPEN ORDER PARAMETER.    RRG03000
         BE    IR1030F            DO NOT PRT OPEN ORDERS.             RRG03010
         CLC   PRTOPORD,IRCHAR1                                       RRG03020
         BE    IR1030F            DO PRINT OPEN ORDERS.               RRG03030
         MVC   ERRCODE,IRER27     PRT OPEN ORDER PARAM. WRONG.        RRG03040
         BAL   9,IR1059                                               RRG03050
IR1030F  CLC   PRTNET,IRBLANK     TEST PRT NET PARAMETER.             RRG03060
         BE    IR1030H            DO NOT PRINT NET                    RRG03070
         CLC   PRTNET,IRCHAR1                                         RRG03080
         BE    IR1030G            DO PRINT NET                        RRG03090
         MVC   ERRCODE,IRER28     PRT NET PARAM. WRONG.               RRG03100
         BAL   9,IR1059                                               RRG03110
IR1030G  CLC   PARNET,IRCHAR1     PRT NET,TEST IF CALC. NET           RRG03120
         BE    IR1030H            PRT NET PARAM O.K.                  RRG03130
         MVC   ERRCODE,IRER29     HAVE SPECIFIED PRINT NET BUT NOT    RRG03140
         BAL   9,IR1059           CALC. NET   ERROR.                  RRG03150
IR1030H  CLC   PRTPLORD,IRBLANK   TEST PRT PLAN ORDER PARAMETER.      RRG03160
         BE    IR1030J            DO NOT PRINT PLAN ORDERS.           RRG03170
         CLC   PRTPLORD,IRCHAR1                                       RRG03180
         BE    IR1030I            DO PRINT PLAN ORDERS                RRG03190
         MVC   ERRCODE,IRER30     PRT PLAN ORDER PARAM. WRONG.        RRG03200
         BAL   9,IR1059                                               RRG03210
IR1030I  CLC   PARPLAN,IRBLANK    PRT PLAN ORD,TEST IF CALC PLAN      RRG03220
         BNE   IR1030J            ORD. BRANCH IF O.K.                 RRG03230
         MVC   ERRCODE,IRER31     HAVE SPECIFIED PRT PLAN ORDER       RRG03240
         BAL   9,IR1059           BUT NOT CALC. PLAN ORDER. ERROR.    RRG03250
IR1030J  CLC   PRTOFSET,IRBLANK   TEST PRINT OFFSET PARAMETER.        RRG03260
         BE    IR1032             DO NOT PRINT OFFSET.                RRG03270
         CLC   PRTOFSET,IRCHAR1                                       RRG03280
         BE    IR1030K            DO PRINT OFFSET                     RRG03290
         MVC   ERRCODE,IRER32     PRT OFFSET PARAMETER WRONG.         RRG03300
         BAL   9,IR1059                                               RRG03310
IR1030K  CLC   PAROFFST,IRCHAR1   PRT OFFSET,TEST FOR CALC. OFFSET    RRG03320
         BE    IR1032             PRT OFFSET PARAM. O.K.              RRG03330
         MVC   ERRCODE,IRER33     HAVE SPECIFIED PRT OFFSET BUT       RRG03340
         BAL   9,IR1059           NOT CALC. OFFSET. ERROR.            RRG03350
         B     IR1032                                                 RRG03360
IRBLANK  DC    C' '                                                   RRG03370
IRCHAR2  DC    C'2'                                                   RRG03380
IRER05   DC    C'05'                                                  RRG03390
IRER06   DC    C'06'                                                  RRG03400
IRER07   DC    C'07'                                                  RRG03410
IRER09   DC    C'09'                                                  RRG03420
IRER10   DC    C'10'                                                  RRG03430
IRER11   DC    C'11'                                                  RRG03440
IRER12   DC    C'12'                                                  RRG03450
IRER13   DC    C'13'                                                  RRG03460
IRER14   DC    C'14'                                                  RRG03470
IRER15   DC    C'15'                                                  RRG03480
IRER16   DC    C'16'                                                  RRG03490
IRER17   DC    C'17'                                                  RRG03500
IRER18   DC    C'18'                                                  RRG03510
IRER24   DC    C'24'                                                  RRG03520
IRER25   DC    C'25'                                                  RRG03530
IRER26   DC    C'26'                                                  RRG03540
IRER27   DC    C'27'                                                  RRG03550
IRER28   DC    C'28'                                                  RRG03560
IRER29   DC    C'29'                                                  RRG03570
IRER30   DC    C'30'                                                  RRG03580
IRCHAR3  DC    C'3'                                                   RRG03590
IRER08   DC    C'08'                                                  RRG03600
IRCHAR1  DC    C'1'                                                   RRG03610
IRPACK1  DC    P'1'                                                   RRG03620
IRER31   DC    C'31'                                                  RRG03630
IRER32   DC    C'32'                                                  RRG03640
IRER33   DC    C'33'                                                  RRG03650
NOERRSW  DC    X'00'                                                  RRG03660
NOERR01  DC    CL2'50'            RECALTN = NO                        RRG03670
NOERR02  DC    CL2'51'            NETREQT = NO                        RRG03680
NOERR03  DC    CL2'52'            PLANORS = NONE                      RRG03690
NOERR04  DC    CL2'53'            PLANORS = NONE & PLANORD = NO       RRG03700
NOERR05  DC    CL2'54'            OFFSETR = NO                        RRG03710
NOERR06  DC    CL2'55'            PLANORD = NO & CONVPLN = NO         RRG03720
NOERR07  DC    CL2'56'            PLANORD = NO & CONVPLN = NO         RRG03730
NOERR08  DC    CL2'57'            OFFSETR = NO                        RRG03740
NOERR09  DC    CL2'58'            PRNISEQ = NO                        RRG03750
NOERR10  DC    CL2'59'            CONVPLN = NO                        RRG03760
NOERR11  DC    CL2'60'            CONVPLN = NO                        RRG03770
NOERR12  DC    CL2'61'            OPENORD = NO                        RRG03780
*                                                                     RRG03790
* SWITCHES TO TEST VALIDITY OF RUN PARAMS VS. CUSTOMIZED PARAMS       RRG03800
*                                                                     RRG03810
TSTRQAL  DC    X'00'     REQUIREMENTS ALTERATION                      RRG03820
TSTNTRQ  DC    X'00'     NET REQUIREMENTS                             RRG03830
TSTPLOR  DC    X'00'     PLANNED ORDERS                               RRG03840
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TSTSTPO  DC    X'00'        STORE PLANNED ORDERS                RBG03850
TSTOFST  DC    X'00'        OFFSET                              RBG03860
TSTRNTY  DC    X'00'        RE-ENTRY                            RBG03870
TSTORNY  DC    X'00'        OFFSET RE-ENTRY                     RBG03880
TSTPSEQ  DC    X'00'        PRINT SEQUENTIAL                    RBG03890
TSTPENY  DC    X'00'        PRINT SEQ ALL PREVIOUS INTERRUPTS   RBG03900
TSTPOOR  DC    X'00'        PRINT OPEN ORDERS                   RBG03910
*                                                               RBG03920
*                                                               RBG03930
*  REST OF INITIALIZATION START HERE                            RBG03940
*                                                               RBG03950
IRI060   LR    10,11                 SAVE BASE REGISTER         RBG03960
         USING RPFCBS,1                                         RBG03970
IRI061   EQU   *                                                RBG03980
.* TEST FOR CARD INPUT                                          RBG03990
         AIF   (&ALINPUT(2) EQ 'CARD20').I460                   RBG04000
         AIF   (&ALINPUT(3) EQ 'CARD20').I460                   RBG04010
         AGO   .I461                                            RBG04020
.I460    MVI   PADCLCSW,X'00'        SET PROCESS LAST CARD SW OFF RBG04030
.* TEST FOR CONVERSATIONAL PLANNING LOGIC USED                  RBG04040
.I461    AIF   (&ALCONVPLNG NE 'YES').I462                      RBG04050
         CLI   PARRENTY,X'00'        TEST FOR RE-ENTRY          RBG04060
         BE    IRI062                NO                         RBG04070
*  INIT. FOR RE-ENTRY RUN            YES                        RBG04080
         L     11,ADFEILTM           LOAD STORED LEVEL TABLE    RBG04090
         BALR  14,11                 FROM DISK STORAGE FILE     RBG04100
         LR    11,10                 RESTORE BASE REGISTER      RBG04110
         B     IRI064                                           RBG04120
*                                                               RBG04130
IRI062   EQU   *                                                RBG04140
*  INIT. FOR NON RE-ENTRY RUN                                   RBG04150
.I462    ANOP                                                   RBG04160
         LA    6,MAXLEVNO+1          INITIALIZE                 RBG04170
         LA    5,LOSKADCH            LEVEL TABLE                RBG04180
IRI063   MVC   0(L'LOSKADDR,5),APPEND  WITH                     RBG04190
         LA    5,L'LLTABENTRY(5)     END OF CHAIN               RBG04200
         BCT   6,IRI063              CONSTANT                   RBG04210
         MVC   APLEVCTR,ZERO         INIT SET LEVEL COUNTER TO ZERO RBG04220
         LA    5,LTABLE              INIT SET LEVEL TABLE ADDR CTR RBG04230
         ST    5,LVTBLCTR               TO START ADDR OF TABLE  RBG04240
         L     1,SAVFCBAD            LOAD SAVED FCB ADDR IN BASE REG1 RBG04250
         LH    6,RPFRRACN            IN ORDER TO                RBG04260
         AH    6,FRRHONE             UPDATE MASTER RUN ACTIVITY NO. RBG04270
         STH   6,FRRRACN                                        RBG04280
         MVC   MSPI,MTCLOSE          CLOSE I/M FILE             RBG04290
         L     11,ARPMCALT           IN ORDER TO UPDATE MASTER RUN RBG04300
         BALR  14,11                 ACTIVITY NO. ON DISK FCB   RBG04310
         LR    11,10                 RESTORE BASE REGISTER      RBG04320
         MVC   MSPI,MTOPEN                                      RBG04330
         L     11,ARPMCALT           RE-OPEN I/M FILE           RBG04340
         BALR  14,11                                            RBG04350
         LR    11,10                 RESTORE BASE REGISTER      RBG04360
*                                                               RBG04370
IRI064   L     1,SAVFCBAD            LOAD SAVED FCB ADDR IN BASE REG1 RBG04380
         MVC   RPCURACN,L'FRRACN     SAVE CURRENT RUN ACT NO.   RBG04390
         CLI   ASWITCH,X'00'         TEST SW FOR CLEAR INDICATION RBG04400
         BNE   IRI075                DONT CLEAR - GO TO ROUTINE EXIT RBG04410
*  CLEAR GROSS REQ. AND STORED PLANNED ORDERS FROM RECORDS AS REQ. RBG04420
         AIF   (&ALCONVPLNG EQ 'YES').I463A                     RBG04421
         AIF   (&ALPEGGING EQ 'YES').I463A                      RBG04422
         AGO   .I463B                                           RBG04423
.I463A   AIF   (&ALGROSSRT(2) EQ 'YES').I463B                   RBG04424
         AIF   (&ALPLANORDS EQ 'YES').I463B                     RBG04425
         AGO   .I468                                            RBG04426
.I463B   ANOP                                                   RBG04427
*  SEQUENTIAL RETRIEVAL OF I/M RECORD                           RBG04430
IRI065   L     11,ARPMSEQR                                      RBG04440
         BALR  14,11                                            RBG04450
         B     IRI068                EOF RETURN                 RBG04460
         LR    11,10                 NORMAL RETURN - RESTORE BASE REG RBG04470
         CLI   RPFRRBSW,X'00'        TEST FOR I/O ERROR         RBG04480
         BE    IRI066                NO ERROR                   RBG04490
         L     11,ARPABNEO           ERROR - GO TO ABNORMAL EOJ RBG04500
         BR    11                                               RBG04510
*                                                               RBG04520
IRI066   NI    RRPF,X'7F'            SET BIT 0 RP FLAG OFF IN I/M RBG04530
.* TEST FOR I/M USED FOR STORING GROSS REQUIREMENTS             RBG04540
         AIF   (&ALGROSSRT(2) NE 'YES').I465                    RBG04550
.* TEST FOR USER EXIT ELECTED TO SAVE RECORDS GROSS REQ.        RBG04560
         AIF   (&ALEXITOT(2) NE 'YES').I464                     RBG04570
*  USER EXIT TO SAVE RECORDS GROSS REQ.                         RBG04580
         L     11,AEXIT07                                       RBG04590
         BALR  14,11                                            RBG04600
         LR    11,10                 RESTORE BASE REGISTER      RBG04610
*                                                               RBG04620
.I464    BAL   14,IRI071             GO TO CLEAR RECORDS GROSS REQ. RBG04630
.* TEST FOR I/M USED FOR STORING PLANNED ORDERS                 RBG04640
.I465    AIF   (&ALPLANORDS NE 'YES').I467                      RBG04650
.* TEST FOR USER EXIT ELECTED TO SAVE RECORDS PLANNED ORDERS    RBG04660
         AIF   (&ALEXIT(12) NE 'YES').I466                      RBG04670
*  USER EXIT TO SAVE RECORDS PLANNED ORDERS                     RBG04680
         L     11,AEXIT12                                       RBG04690
         BALR  14,11                                            RBG04700
         LR    11,10                 RESTORE BASE REGISTER      RBG04710
*                                                               RBG04720
.I466    BAL   14,IRI073             GO TO CLEAR RECORDS PLANNED ORD RBG04730
.I467    ANOP                                                   RBG04740
*  UPDATE I/M RECORD ON DISK                                    RBG04750
IRI067   L     11,ARPMSEQU                                      RBG04760
         BALR  14,11                                            RBG04770
         LR    11,10                 RESTORE BASE REGISTER      RBG04780
         CLI   RPFRRBSW,X'00'        TEST FOR I/O ERROR         RBG04790
         BE    IRI065                NO ERROR - GO GET NEXT RECORD RBG04800
         L     11,ARPABNEO           ERROR - GO TO ABNORMAL EOJ RBG04810
         BR    11                                               RBG04820
*                                                               RBG04830
.I468    ANOP                                                   RBG04840
IRI068   EQU   *                                                RBG04850
         AIF   (&ALGROSSRT(2) EQ 'YES').I468A                   RBG04860
         AIF   (&ALPLANORDS EQ 'YES').I468A                     RBG04870
         B     IRI075                GO TO RETURN TO MAINLINE PROGRAM RBG04880
         AGO   .I475                                            RBG04890
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.IR68A   ANOP
*  SEQUENTIAL RETRIEVAL OF S/M RECORD
         L     11,ARPRSEQR
         BALR  14,11
         B     IR1075                  EOF RETURN
         LR    11,10                   NORMAL RETURN - RESTORE BASE REG
         CLI   RPERRRSW,X'00'          TEST FOR I/O ERROR
         BE    IR1069                  NO ERROR
         L     11,ARPRABND             ERROR - GO TO ABNORMAL EOJ
         BR    11
*
IR1069   EQU   *
.* TEST FOR S/M USED FOR STORING GROSS REQUIREMENTS
         AIF   ('&RGROSSRTA' NE '&SAO').IR70
.* TEST FOR USER EXIT ELECTED TO SAVE RECORDAS GROSS REQ.
         AIF   ('&REXIT07A' NE 'YES').IR69
*  USER EXIT TO SAVE RECORDAS GROSS REQ.
         L     11,AEXIT07
         BALR  14,11
         LR    11,10                   RESTORE BASE REGISTER
*
.IR69    BAL   14,IR1071               GO TO CLEAR RECORDAS GROSS REQ.
.* TEST FOR S/M USED FOR STORING PLANNED ORDERS
.IR70    AIF   ('&RPLANORDA' NE '&SAO').IR72
.* TEST FOR USER EXIT ELECTED TO SAVE RECORDAS PLANNED ORDERS
         AIF   ('&REXIT12A' NE 'YES').IR71
*  USER EXIT TO SAVE RECORDAS PLANNED ORDERS
         L     11,AEXIT12
         BALR  14,11
         LR    11,10                   RESTORE BASE REGISTER
*
.IR71    BAL   14,IR1073               GO TO CLEAR RECORDAS PLANNED ORD
.IR72    ANOP
*  UPDATE S/M RECORD ON DISK
IR1070   L     11,ARPRSEQU
         BALR  14,11
         LR    11,10                   RESTORE BASE REGISTER
         CLI   RPERRRSW,X'00'          TEST FOR I/O ERROR
         BE    IR1068                  NO ERROR - GO GET NEXT RECORD
         L     11,ARPRABND             ERROR - GO TO ABNORMAL EOJ
         BR    11
*
.IR73    ANOP
*  CLEAR RECORDAS GROSS REQ. FIELDS
IR1071   EQU   *
.* TEST FOR GR. REQ. DATE FORMAT
         AIF   ('&RGROSSDTA' EQ '&TRRDAM').IR74
         LA    6,CGROSSNO
         AGO   .IR75
.IR74    LA    6,CMONTHPR
.IR75    LA    5,RPGROSS
IR1072   MVC   0(L'RPGROSS,5),DADDBLK
         LA    5,L'RPGROSS(5)
         BCT   6,IR1072
         BR    14                      RETURN TO CALLER
*
.* TEST FOR PLANNED ORDERS STORED
         AIF   ('&RPLANORDA' EQ '&NODA').IR76
*  CLEAR RECORDAS PLANNED ORDERS FIELDS
IR1073   LA    6,CPLANONO
         LA    5,RPRPM
IR1074   MVC   0(L'RPRPM,5),DADDBLK
         LA    5,L'RPRPM(5)
         BCT   6,IR1074
         BR    14                      RETURN TO CALLER
*
*
.IR76    ANOP
*  END OF ROUTINE - RETURN TO MAINLINE PROGRAM
IR1075   L     14,IRSAVE14
         BR    14
*
         SPACE FOR
*
*
*        CONSTANTS SECTION
*
IRKHZERO DC    H'0'
IRKHONE  DC    H'1'
         AIF   ('&REXIT07A' NE 'YES').IR77
AEXIT07  DC    A(EXIT07)
.IR77    AIF   ('&REXIT12A' NE 'YES').IR78
AEXIT12  DC    A(EXIT12)
.IR78    ANOP
         DROP  11
         MEND

         MEND
```

ECJ DISPLAY

RPD005RC

DIRECTORIO DE ALUMNOS DEL CURSO: "SEMINARIO SOBRE PLANEACION DE REQUERIMIENTOS DE MATERIAL" , DEL 4 AL 8 DE SEPTIEMBRE.

1.	SR. DANIEL ACOSTA CASIAN VALLE VERDE No. 5 FRACC. VALLE DEL PARAISO TLALNEPANTLA, EDO. DE MEXICO	ACEROS NACIONALES, S. A. GERENTE CONTROL DE MATERIALES AV. HIDALGO No. 132 TLANEPANTLA, EDO. DE MEXICO TEL. 565-67-00
2.	ING. JORGE ACOSTA DORANTES ATZCAPOTZALCO No. 312 COL. PETROLERA CD. REYNOSA, TAMPS. TEL. 2-24-90	PETROLEOS MEXICANOS JEFE DE LA UNIDAD DE ADMINISTRACION MATERIALES MARINA NACIONAL No. 329 COL. ANAHUAC MEXICO 17, D. F. TEL. 545-74-60 EXT. 3659
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4.	SR. JAVIER ARANDA SOLORZANO FCO. JAVIER MINA No. 44 COL. LOS REYES IXTACALA TLALNEPANTLA, EDO. DE MEXICO	TELEINDUSTRIA ERICSSON, S. A. COORDINADOR DE MECANIZACION DE AV. DR. GUSTAVO BAZ No. 2160 COL. TLALNEPANTLA, EDO. DE MEXICO TEL. 397-81-33 EXT. 1340
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6.	SR. DAVID BENITEZ AMADOR AV. VIA NEPTUNO NO. 100 COL. ARCOS DE LA HACIENDA CUAUTITLAN IZCALLI, MEX. TEL. 576-87-81	INDUSTRIA DE TELECOMUNICACION, S. A. JEFE DE ANALISTAS DE CONTROL DE MATERIALES AV. CIENCIA No. 13 CUAUTITLAN IZCALLI, MEX. TEL. 2-03-40
7.	SR. FELIPE CELORIO C. PROVIDENCIA No. 20 COL. OLIVOS MEXICO 23, D. F. TEL. 564--18-02 574-11-22	PROCESOS Y SISTEMAS DE INFORMACION(ICA) PLANEACION INDUSTRIAL MINERIA No. 145 COL. ESCANDON MEXICO 18, D. F. TEL. 516-04-60 EXT. 211

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