Material requirements planning, a principal approach to manufacturing inventory management, is discussed.

Defined and evaluated are concepts and characteristics of net change, a method that facilitates replanning and provides timely response to change in a transaction-oriented system.

Net change material requirements planning

by Joseph A. Orlicky

Conventional approaches to Material Requirements Planning (MRP) entail an inherent massive data-handling task. Consequently, batch-oriented MRP systems tend to be untimely in their response to change since replanning can be done only periodically—at best, probably once a week. A method of continuous replanning that minimizes the number of accesses to inventory records and bills of material at any given time is presented in this paper. Called *net change*, this approach offers the user the ability to replan at high frequency, or continuously in a transaction-driven system. The COPICS manuals describe a system that is based on net change material requirements planning.[1]

The purpose of this paper is to provide insight to the concepts of net change and to define the essential characteristics of an MRP system that is designed to utilize these concepts. Because net change is a variation on a theme, this theme of conventional material requirements planning, one of the two principal approaches to manufacturing inventory management, is described first, so as to establish proper perspective for the reader.

Manufacturing inventory management

There are two alternate fundamental approaches, and two sets of techniques that a manufacturing enterprise may employ in the management of inventories. They are:

- Statistical inventory control (also called order-point techniques)
- Material requirements planning

Order point is part-based, whereas MRP is product-oriented. Order point utilizes data on the historical demand behavior of a part, in isolation from all other parts. MRP ignores history in looking toward the future as defined by the master production schedule, and works with data on the relationship of components (the bill of material) that make up a product.

The order point has predominated in the past, and it is only recently that MRP has slowly been gaining wider acceptance within the manufacturing industry. The reason for this is historical. The field of inventory management has been conditioned in favor of statistical inventory control because the pioneering theoretical work in this field during the past decades has generally been confined to the areas of order point and order quantity.

This work has been stimulated by the fact that problems of order point and order quantity lend themselves to the application of mathematical-statistical methods which have been known and available for some time. The inventory control problem was perceived as being essentially mathematical, rather than one of massive data handling and data manipulation, the means for which have been unavailable in the past. The chronic problems of manufacturing inventory management are being solved, not through better mathematics, but through better data processing.

dependent and independent demand

The order-point/order-quantity tradition persists in literature and academic curricula, but the fact is that in a manufacturing industry environment the applicability of order point technique is quite limited. The fundamental principle that should serve as a guideline to the applicability of order-point or MRP is the concept of dependent versus independent demand.[2] For purposes of technique selection, the all-important attribute of an inventory is the nature of its demand. Demand for a given inventory item is considered *independent* when it is unrelated to the demand for other items, particularly higher-level assemblies or products. Demand is defined as independent when it is not a function of demand for other inventory items. Independent demand must be forecast.

Conversely, demand is considered *dependent* when it is directly related to, or derives from, the demand for other items or end products. In a typical manufacturing business, the bulk of the total inventory is in raw materials, components, and subassemblies, all largely subject to dependent demand. Such demand can, of course, be calculated. Dependent demand need not, and should not, be forecast.

forecasting

Forecasting is inseparable from order-point techniques. But all forecasting (intrinsic, as well as extrinsic) attempts to use past experience to determine the shape of the future. Forecasting succeeds only to the extent that past performance is repeatable. In a manufacturing environment, however, future demand for a given part may be quite unrelated to its past demand. Forecasting should be the method of last resort, used only when it is not possible to extract, determine, derive demand from something else. In cases of dependent demand forecasting is unnecessary because dependent demand is, by definition, derivable and calculable.

Statistical forecasting addresses the problem of demand magnitude, but in a manufacturing environment an added requirement is that component inventory represent matched sets. When components are forecast and ordered independently of each other, their inventories will not match assembly requirements well, and the cumulative service level will be significantly lower than the service levels of the parts taken individually. This is caused by the adding up of individual forecast errors of a group of components needed for a given assembly.

continuity of demand

Another dimension of demand to be considered is its continuity. Order point assumes relatively uniform usage, in small increments of the replenishment lot size. The underlying assumption of gradual inventory depletion will render the technique invalid when this basic assumption is grossly unrealistic. For components of assembled products, requirements typically are anything but uniform, and depletion anything but gradual. Inventory depletion tends to occur in discrete "lumps" due to lot sizing at higher levels. Because order point basically assumes continuity of demand, subject only to random variations, it also assumes:

- That it is desirable to have at least some inventory on hand at all times
- A need to replenish inventory as soon as depleted

This is not only unnecessary with discontinuous, lumpy demand, but undesirable if inventory levels are to be kept low. The phenomenon of discontinuous demand illustrates the problem of timing of requirements. Inventory management literature appears obsessed with the problem of quantity, while in the real world of manufacturing the question of timing, rather than quantity, is of paramount importance. Order point only implies timing, based as it is on average usage. But average usage data are, for all practical purposes, largely meaningless in an environment of lumpy, dependent demand.

Material requirements planning

The alternative to order point, MRP, provides a correct solution to every one of the problems just mentioned. MRP is a set of techniques expressly designed for the management of inventories subject to dependent demand, and it is therefore vastly more suitable as an inventory control system for manufacturing environments where the bulk of the inventory is subject to this type of demand. It should be noted that while an MRP system is primarily oriented towards dependent demand inventory, it will accommodate independent demand items (such as service parts) also. These are integrated into the system through the technique of Time-Phased Order Point.[3]

MRP evolved from an approach to inventory management in which the following two principles are combined:

- Calculation (versus forecast) of component item demand
- Time-phasing—the addition of the dimension of timing to inventory status data

The term *component item* in MRP comprises all inventory items below the product or end item level. Requirements for end items are stated in the master production schedule and are derived from forecasts, customer orders, field warehouse requirements, interplant orders, and so forth. Requirements for all component items, and their timing, are derived from this schedule by the MRP system.

gross and net requirements

The basic problem in material requirements planning is the conversion of *gross* requirements into *net* requirements, so that the latter can be covered by (correctly timed) shop orders and purchase orders. The netting process consists of a calculation of gross requirements, which is straightforward, and of apportioning existing inventories (quantities on hand and on order) against these gross requirements.

The resulting net requirements are then covered by planned orders, and the order quantities are calculated either discretely (lot for lot) or by employing one of the numerous lot sizing techniques designed to take into account the economics of ordering. The computation of requirements is complicated and constrained by three factors:

- The structure of the product, containing several manufacturing *levels* of materials, parts, and subassemblies
- The timing of end-item requirements (expressed via the master production schedule) across a *planning horizon* of, typically, a year's span or longer
- The different individual *lead times* of inventory items that make up the product

product structure

Product structure imposes the principal constraint on the calculation of net requirements. The mutual parent/component rela-

Figure 1 Parent/component relationship

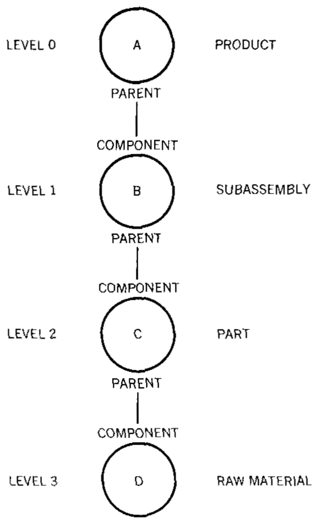
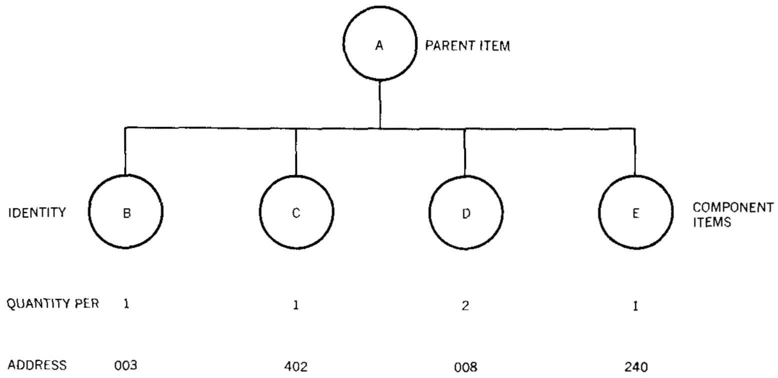
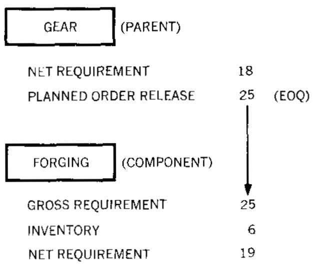


Figure 3 Bill of material



tionship of items on contiguous product levels, as illustrated in Figure 1, necessitates the net requirement and the planned order on the parent level to be computed before the gross requirement on the component level can be determined. The gross requirement for a component derives directly from the planned order quantity of its parent(s), as shown in Figure 2.

Figure 2 Derivation of gross requirement



Requirements for inventory items must therefore be computed on one level at a time, proceeding from top to bottom of the product structure. Net requirements are developed by apportioning (reapportioning) inventories in a level-by-level process. The progression from one product level to another is termed an *explosion.*

The problem in executing the explosion is to identify the component items of a given parent item, and to ascertain the location of their inventory records so that they may be retrieved and processed. The product structure or *bill of material* file guides the explosion process. Product structure data are not operated on but merely consulted by the system. The generic name of the program that organizes and maintains this file is the *bill of material processor.* The retrieval of individual bills of material which contain component identities, quantities per unit of parent item, and pointers or addresses of component item records, as shown in Figure 3, is handled by this program.[4-8]

The bill of material processor also provides certain file edit/analysis functions, including the generation and maintenance of the so-called *low-level code* which identifies the lowest level in the product structure that each item appears on. The use of the low-level code prevents repetitive accessing of item records during the course of the explosion and thus maximizes processing efficiency. There is, however, no *logical requirement* for low-level coding in calculating gross and net requirements.

Figure 4 Timing of a gross requirement

GEAR (PARENT)	PERIOD								
	1	2	3	4	5	6	7	8	
PLANNED ORDER RELEASES				25					

FORGING (COMPONENT)									
REQUIREMENTS				25					

Figure 5 Offsetting for lead time

GEAR LEAD TIME: 2	PERIOD								
	1	2	3	4	5	6	7	8	
NET REQUIREMENTS							18		
PLANNED ORDER RELEASES				25					

LEAD TIME OFFSET

timing of requirements

The parent/component precedence relationship affects not only the quantities, but also the timing of requirements and planned order releases. The timing of a gross requirement for a component item coincides with the timing of an order release planned for its parent, as shown in Figure 4.

lead time offset

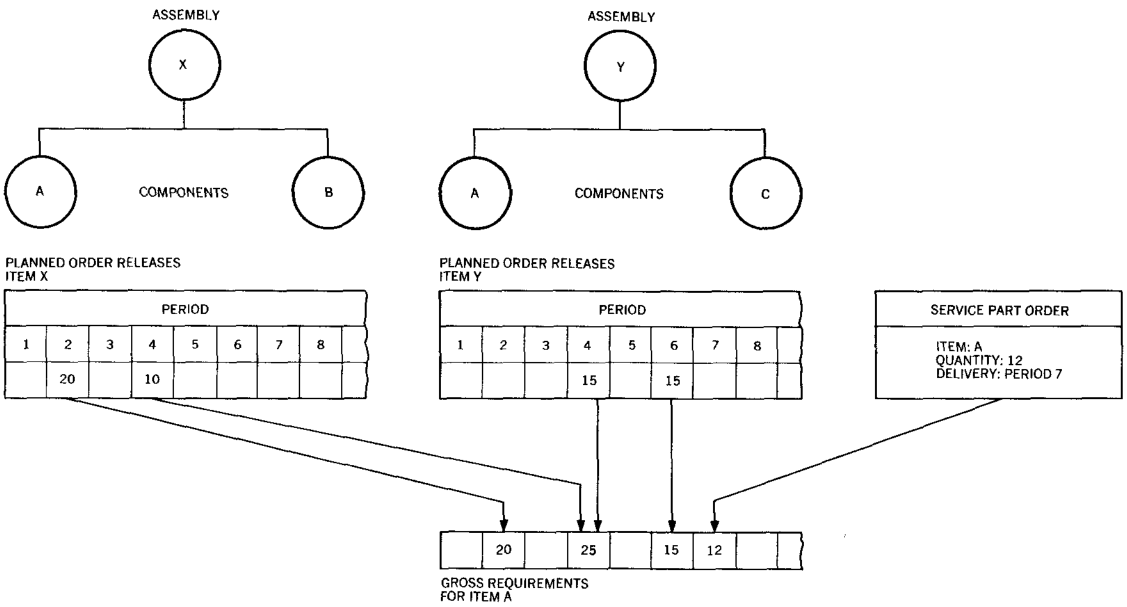
The timing of the planned order release derives from the timing of the net requirement and from the lead time of the item the order is planned for. Positioning the planned order release forward of the time of the net requirement it covers is called *offsetting for lead time*, illustrated in Figure 5.

The gross requirements schedule of an inventory item represents a summary of demands originating from one or more sources, and applicable to various points in time. This is illustrated in Figure 6.

Schedule regeneration

The conventional, and traditional, approach to material requirements planning is based on so called *schedule regeneration*. IBM's Production Information and Control System (PICS) program products utilize the regenerative technique. Under this approach, the entire master production schedule, which constitutes the prime input to an MRP system, is broken down into detailed time-phased requirements for every individual item.[9, 10]

Figure 6 Derivation of gross requirements



Under the regenerative approach:

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

In regenerative material requirements planning, all requirements are exploded in one batch processing run, as the master production schedule is periodically being "regenerated." During this run, the gross and 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 (low-level code determines exceptions) before the next lower level is addressed.

Regeneration, relying mostly on sequential data processing techniques, is a batch processing method that, by definition, must be tied to some periodic frequency. Each schedule regeneration, or explosion, represents a replanning of requirements and an updating of inventory status for all items covered by the MRP system. Intervening changes, if any, in the master production schedule (and in product structure) are accumulated for processing in the next regeneration. A weekly or biweekly replanning cycle is typical of regenerative MRP systems currently installed in industry.[11]

phases of operation

The operation of such systems consists of two distinct, alternating phases:

- The requirements planning (explosion) run
- Intra-cycle file updating

The latter, typically performed daily, consists of the reporting of inventory transactions (stock receipts, issues, scrap, and so forth) to the system and of posting to the individual inventory records. This brings these records up-to-date for purposes of inquiry as well as for the next requirements replanning run. (File maintenance for changes in both product structure and planning factors, such as lead times and scrap allowances, is assumed. It does not constitute a separate phase of operation.)

status data

In a material requirements planning environment, two types of data constitute the plan, or status, of any given inventory item:

- Inventory data
- Requirements data

Inventory data consist of on-hand and on-order quantities, including the timing of the latter. These data are reported to the system and are verifiable by inspection.

Requirements data consist of the quantities and timing of gross requirements, net requirements, and planned order releases. These data are computed and are verifiable only through recomputing.

inventory status

Under the regenerative approach to MRP, the requirements data are not a logically integral part of the item master record, that is, the inventory status record. This means that item-inventory status is actually being established and displayed in two versions:

- Inventory status in its narrower sense
- Inventory status in its broader sense

The first, consisting of inventory data and, in some implementations, "allocated on hand" data (discussed in a later section), is being maintained via the file update process at a relatively high frequency, such as daily. The second, which also includes requirements data, is, strictly speaking, not being maintained but rather reestablished, at a different, lower frequency, such as weekly. The output of the requirements planning run that reestablishes this status is typically printed as a report rather than stored. When it is stored, it is for purposes other than maintenance.

Note that in the file-update phase a given transaction updates only the one item record that it affects directly. Because of the parent/component relationship between items, and because of the logical link between the parent's planned order and the component's gross requirement, certain transactions (such as scrap) may upset the status of the item in a way that, in fact, affects items on another level also.

In a regenerative MRP system, however, the file update program is oblivious of inter-item relationships, which are designed to be reestablished by the regeneration program during a requirements planning run. Thus an inventory transaction, under a regenerative system, never triggers an explosion into a lower product level. This allows a gradual deterioration in the validity of requirements data to take place following each requirements planning run.

Inherent to schedule regeneration, always a big job, is the task of massive data handling which entails a delay in obtaining the results of the requirements planning run and dictates that the job be done periodically, that is, at economically reasonable intervals. This causes the system to be out-of-date, to some degree, at all times.

How serious a disadvantage this represents in a given case depends on:

- The environment in which the MRP system must operate
- The uses to which it is being put

environment

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 an environment of this kind there is a strong need for timeliness of response to change, but a regenerative MRP 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.

uses

In a more stable environment, a regenerative MRP system may function satisfactorily, as far as material requirements are concerned. But MRP is more than just an inventory system. If it is put to its full and proper use, it actually functions on three distinct levels:

- Planning and controlling inventories
- Providing the basis (through its planned order schedules) for the planning of capacity requirements
- Maintaining priorities of open shop orders (and purchase orders) up-to-date and thus valid

The capacity planning and priority updating functions of MRP are beyond the scope of this paper. It is necessary to point out, however, that the shop priority maintenance function represents a vitally important capability of any time-phased MRP system. Every such system has an inherent, built-in capability to reevaluate and revise all open order due dates. It is these 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 shop priorities are to be valid at all times, order due dates must be up-to-date at all times.

An MRP system that replans in weekly (or longer) 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 difficult to see how shop priorities can be kept constantly valid by the *formal* system. This function must then be taken over by an *informal* system of assembly shortage lists and "hot order" expediting that can (and in most cases does) 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, because the business could not afford to wait for the next requirements planning run, days or perhaps weeks away.

replanning frequency

The frequency of replanning is a critical variable in the use of an MRP 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. To make it feasible to replan requirements with adequate frequency, a solution to the problem of data processing economics (the scope of the replanning job, its duration, the volume of its output) must first be found, and the delay inherent in any massive batch processing run must be avoided.

This indicates that a non-regenerative approach to MRP is required—an approach that will minimize the number of inventory records and bills of material that must be accessed during the replanning process and that will limit the volume of (automatically generated) output to notices of currently required action. Such an approach is embodied in an MRP system designed on the net change concept.[11]

Net change material requirements planning

The function that the requirements planning run provides is essential. The explosion cannot be eliminated or circumvented, but it can be stretched out. Net change MRP manifests itself through consecutive, partial explosions performed with high frequency, in substitution for a full explosion performed periodically at relatively long intervals.

partial explosion

The partial explosion is the key to the practicability of the net change approach, as it minimizes the scope of the requirements planning job at any one time, and thus permits frequent replanning. Because the explosion is only partial, it automatically limits the volume of the resulting output. Under the net change approach, the explosion is partial in two senses:

- Only part of the master production schedule is subject to explosion at any one time
- The effect of transaction-triggered explosions is limited to lower-level components of the item providing the stimulus for the explosion

In the discussion that follows, these two aspects of a net change MRP system will be reviewed separately.

master schedule continuum

The net change concept views the master production schedule as one plan in continuous existence, rather than as successive versions or issues of the plan. The master production schedule can be updated at any time, by adding or subtracting the net difference from its previous status. Periodic issues of a new schedule are treated the same way, in effect as a special case of updating for change.

This concept is illustrated in Figure 7. The schedule is envisioned to resemble a Chinese scroll unwinding with passage of time. Each "bucket" in the master production schedule grid contains either a zero or some positive value. The schedule extends indefinitely into the future with all buckets beyond the planning horizon having zero contents. Passage of time brings segments of the future within the planning horizon, at which time the buckets' contents are normally changed (via the issue of a new schedule) from zero to a positive value.

Updating and changing the master production schedule are equivalent under the net change concept. Because either is ef-

Figure 7 Master schedule continuum

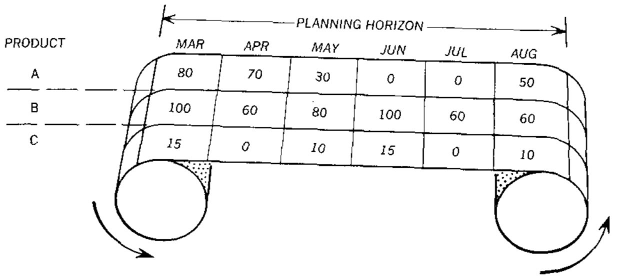


Figure 8 Updating and changing the master production schedule

A

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

B

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

C

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

fected by means of addition or subtraction of the net difference relative to its previous status, the task of replanning is minimized. This treatment of the master production schedule was pioneered by American Bosch of Springfield, Massachusetts, in a biweekly-batch MRP system implemented in 1959.[12] Figure 8 illustrates this approach. If a six-month schedule appeared in March as in Figure 8A, and in April as in Figure 8B, the difference from previous status nets out as shown in Figure 8C. This is the *net change* that is processed (exploded) by the MRP system on whatever day the new schedule goes into effect.

In the example, out of a total of 18 master production schedule buckets within the planning horizon, 15 remain unaffected. The schedule for product B continues unchanged. In this case, the data processing job on a net change basis is only a fraction of the job that a regenerative MRP system would have to perform. Under the schedule-regeneration approach, the contents of all 18 buckets are input to the system and all inventory records as well as bills of material related to products A, B, and C have to be accessed and processed.

An additional important point is represented by the fact that if 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.

item-status updating

The principle of net change—the processing of only the difference from previous status—extends also to item-status updating. This makes it feasible to maintain inventory status in its broader sense (as defined previously) up-to-date for all items covered by the system, without regenerating any of the data. Gross requirements, net requirements, and planned order release data are not reconstituted but merely modified, updated. Under the net change approach, these data are updated in the process of posting inventory transactions to item records. The function of file updating, limited under the regenerative approach to on-hand and on-order data, is expanded to cover all of the status data in the item record.

This requires that time-phased requirements data be logically integrated with inventory data, and that a permanent requirements file be created within the system. In contrast to the regenerative method, this file is stored for purposes of maintenance by the net change MRP system. Because the requirements for a given item derive from the quantities and timing of planned order releases of its parent items, the planned order release data are part of this file.

The logical inventory status record that allows all of the pertinent data to be correctly ordered and displayed in a compact format while providing a logical link to related component (lower level) records, is shown in Figure 9. This time-phased inventory record is the basic foundation of a net change MRP system.

In the example, the gross requirements for the item, a total of 59 units, are time-phased, that is, apportioned by period. There is an open order for 23 units due in period 3. The current quantity on hand of 14 is projected forward, the quantities representing stock on hand at the end of each period. In period 7 the on-hand quantity turns negative, indicating lack of coverage, or a *net requirement* of 18. Following this period, gross requirements

Figure 9 Time-phased inventory record

LEAD TIME: 2	CONTROL BALANCE	PERIOD								
ORDER QUANTITY: 25										
ALLOCATED		1	2	3	4	5	6	7	8	
REQUIREMENTS		10	2		10	13		20	4	
SCHEDULED RECEIPTS				23						
ON HAND	14	4	2	25	15	2	2	−18	−22	
PLANNED ORDER RELEASES					25					

equal net requirements. The net requirement for period 8 is 4. The total net requirement for the planning horizon is 22. Coverage of the net requirements is provided by the planned order release for 25, offset for lead time to take place in period 4.

Two concepts related to inventory status characterize a net change MRP system:

- Record balance
- Inter-level equilibrium

item-record balance

The record in Figure 9 is in balance, in the sense that the projected on-hand quantities correspond to existing gross requirements and scheduled receipts, and that the next replenishment order is correctly determined as to both quantity and timing. The next inventory transaction will change the status and may disturb this balance. In a net change MRP environment the record is rebalanced, that is, the projected on-hand quantities (net requirements) are recalculated, and the planned order releases are realigned or changed, as required, before the record is returned to file. All inventory records on file are in individual balance at all times.

In the Figure 9 example, if the open order for 23 is reduced to 20 following the scrapping of 3 pieces, the net requirements will both increase and move forward in time. To restore balance, the planned order release will have to be rescheduled. The rebalanced record is shown in Figure 10.

inter-level equilibrium

The concept of inter-level or file equilibrium extends the principle of balance to sets of records that are logically related. This means that gross requirements for every item must correspond to the quantities and timing of planned order releases of their parent items.

Because the timing of the planned order release for the item in the example has changed (from period 4 in Figure 9 to period 2 in Figure 10), the gross requirements for its component items have

Figure 10 Rebalanced inventory record

LEAD TIME: 2 / ORDER QUANTITY: 25	CONTROL BALANCE	PERIOD								
ALLOCATED		1	2	3	4	5	6	7	8	
REQUIREMENTS		10	2		10	13		20	4	
SCHEDULED RECEIPTS				20						
ON HAND	14	4	2	22	12	−1	−1	−21	−25	
PLANNED ORDER RELEASES			25 ←							

Figure 11 Net change in gross requirements

	PERIOD								
COMPONENT ITEMS	1	2	3	4	5	6	7	8	
CHANGE IN REQUIREMENTS		+25		−25					

also changed and the former equilibrium between parent and component item records has been upset. To restore equilibrium, the system immediately processes the net change in the components' gross requirements. Figure 11 represents this net change.

The restoration of inter-level equilibrium necessitates a (partial) explosion of requirements. Lower-level item records are identified via the product structure file and are retrieved. They are then reprocessed so as to realign their logical linkage to the parent item, and to reestablish a balance in the status of the individual items. To the extent that this reprocessing changes the planned order release schedules of the component items, the explosion progresses further down the product structure, through as many levels as required. This is illustrated in Figure 12. The item record file depicted in Figure 12A is in equilibrium. Assuming that the next transaction was a customer return of 4 units of assembly A (Figure 12B), this upset the equilibrium between records A and B. Following its restoration, the equilibrium between B and C was upset in turn, was restored, and so on. In this example, a single transaction has caused an explosion into three lower levels.

The processing logic illustrated here is the same as that used in the regenerative approach. *Transaction-triggered explosions*, however, are a unique characteristic of a net change MRP system. The principle of inter-level equilibrium demands that inventory transactions, when presented to the system, be fully processed. The updating process triggered by a given transaction is completely carried out downward through the product structure, as required. Whenever a change in status of one item (caused by a

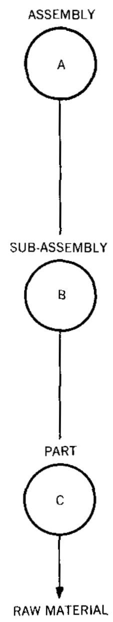
Figure 12 Restoration of inter-level equilibrium

A

		PERIOD							
		1	2	3	4	5	6	7	8
REQUIREMENTS		3		5	8		2	4	9
SCHEDULED RECEIPTS					4				
ON HAND	19	16	16	11	7	7	5	1	-8
PLANNED ORDERS							8		

REQUIREMENTS							8		
SCHEDULED RECEIPTS									
ON HAND	3	3	3	3	3	3	-5	-5	-5
PLANNED ORDERS				5					

REQUIREMENTS				5					
SCHEDULED RECEIPTS									
ON HAND	2	2	2	-3	-3	-3	-3	-3	-3
PLANNED ORDERS		3							



B

		PERIOD							
		1	2	3	4	5	6	7	8
		3		5	8		2	4	9
					4				
	23	20	20	15	11	11	9	5	-4
							4		

−4

							4		
	3	3	3	3	3	3	-1	-1	-1
				1					

−4

				1					
	2	2	2	1	1	1	1	1	1

−3

single transaction entry) affects other related items on lower levels, all of the respective records, regardless of their number, are updated as a result of this entry. This means that transactions may be entered in random sequence and at random times.

transaction-oriented system

A net change MRP system is transaction-oriented and can be transaction-driven. Because the system updates inventory status in its broader sense, including requirements data, any entry (input) posted to an item record that affects the time-phased data acts as a transaction. All such entries, encompassing the following, are viewed and treated as transactions by the system:

- Inputs from the master production schedule
- Gross requirements alterations resulting from changes in planned order release schedules on the parent level (internally generated transactions)
- Gross requirements alterations resulting from external, direct entry to a lower-level item record (for example, a service part order for a component)
- Traditional inventory transactions

single inventory management function

In a net change MRP system there is no distinction between the file updating and requirements planning phases. Under the net change approach, inventory control (or inventory accounting) and requirements planning are fused into a single inventory management function.

Figure 13 Inventory record at the beginning of period 2

LEAD TIME: 2 / ORDER QUANTITY: 25	CONTROL BALANCE	PERIOD								
ALLOCATED		2	3	4	5	6	7	8	9	
REQUIREMENTS		2		10	13		20	4		
SCHEDULED RECEIPTS			20							
ON HAND	4	2	22	12	−1	−1	−21	−25	−25	
PLANNED ORDER RELEASES		25								

ACTION BUCKET

In current implementations of net change MRP systems, neither changes in product structure nor changes in planning factors (such as lead time or lot-sizing algorithm) are being treated as transactions; that is to say, their entry in the course of item master file maintenance does not set off the replanning process. These types of change are reflected in the inventory status only following the next transaction entry against the item affected.

allocated on-hand quantity

The requirement of inter-level equilibrium in a net change environment creates one special demand on the system's processing logic. When a planned order for a manufactured item is released (transformed from a planned order release to a scheduled receipt), the required quantities of its components must be *allocated* in the respective component records, as the following explanation will show.

Order release action takes place when a planned order becomes *mature*, that is, when the timing of its planned release coincides with the current period. In the time-phased inventory record the first planned order release field is correspondingly called the *action bucket*. Passage of time (or rebalancing of the record) brings the planned order quantity into this bucket. The example in Figure 13 shows how the record presented in Figure 10 would appear at the beginning of period 2. Because the action bucket is full, the system will signal the need for order release action. After the transaction reporting this action has been posted, the record appears as shown in Figure 14. Because the contents of the action bucket have been reduced by 25, the principle of inter-level equilibrium demands that gross requirements at the next lower level be reduced accordingly.

This reduction would distort the status of the lower-level components because, at parent order release time, the component gross requirements have not yet been satisfied physically. The corresponding quantities of these components (intended for disbursement in support of the parent order) are still on hand at the moment. Due to the time lag between order release and the fill-

Figure 14 Release of the planned order

LEAD TIME: 2 / *ORDER QUANTITY:* 25	CONTROL BALANCE	PERIOD								
ALLOCATED		2	3	4	5	6	7	8	9	
REQUIREMENTS		2		10	13		20	4		
SCHEDULED RECEIPTS			*20*	25						
ON HAND	4	2	22	37	24	24	4	0	0	
PLANNED ORDER RELEASES										

−25

Figure 15 Distortion of component item status

A ORIGINAL STATUS OF COMPONENT ITEM

		PERIOD								
		2	3	4	5	6	7	8	9	
REQUIREMENTS		25				60				
SCHEDULED RECEIPTS										
ON HAND	65	40	40	40	40	−20	−20	−20	−20	
PLANNED ORDER RELEASES			20							

B STATUS DISTORTED FOLLOWING RELEASE OF PARENT ORDER

−25

REQUIREMENTS						60				
SCHEDULED RECEIPTS										
ON HAND	65	65	65	65	65	5	5	5	5	
PLANNED ORDER RELEASES										

−20

ing of the respective material requisition (component disbursement), a distortion of component item status would occur. This is illustrated in Figure 15.

In Figure 16A the problem is solved by incrementing the allocation field in the item record by the quantity of gross requirement reduction at parent order release time. The quantity of stock on-hand allocated (to released parent orders), sometimes called *uncashed requisitions*, serves as a substitute gross requirement added to the first period for purposes of calculating the projected on-hand quantities. Following the physical disbursement of the item, the respective transaction reduces the content of both the on-hand and the allocated fields, by the same amount. This is shown in Figure 16B.

The *logical requirement* for allocating on-hand quantities is yet another characteristic of a net change MRP system. Under the

Figure 16 Function of the allocation field

A COMPONENT RECORD UPDATED FOR PARENT ORDER RELEASE

+25 –25

			PERIOD							
ALLOCATED	25		3	4	5	6	7	8	9	
REQUIREMENTS						60				
SCHEDULED RECEIPTS										
ON HAND	65	40	40	40	40	–20	–20	–20	–20	
PLANNED ORDERS			20							

B FOLLOWING PHYSICAL DISBURSEMENT

–25 –25

ALLOCATED										
REQUIREMENTS						60				
SCHEDULED RECEIPTS										
ON HAND	40	40	40	40	40	–20	–20	–20	–20	
PLANNED ORDERS			20							

regenerative approach, the allocation procedure is optional. If at order-release time the order is entered into the open-order file, allocation is necessary. If such entry is delayed until after component disbursement, however, allocation is not required.

control of performance to plan

An interesting, and useful, feature of a net change MRP system are the *control balance* fields in the time-phased record shown in Figures 9, 10, 13, and 14. Through the use of these fields the system is able to monitor performance to plan and to generate management information for control of this performance.

As the system updates the item-record file for passage of time (normally, once a week with 1-week time buckets), the contents, if any, of the buckets representing the period just passed are "shifted" into the control-balance fields, except for the on-hand data. The control balances then represent delinquent performance. In Figure 13, for example, performance planned for period 2 calls for 2 units to be consumed (disbursed, shipped) and 25 units to be ordered. If actual performance had turned out to be 1 (assuming that the parent order for 2 was released but only 1 unit of this component was disbursed) and 0, respectively, the record would appear as in Figure 17. In this case, the delinquent planned order release quantity has also been added to the contents of the period 3 bucket, for greater ease of evaluation by the user.

Negative quantities can be recorded in the control balance fields whenever a transaction indicates premature (or excessive) performance. For example, if, following the status shown in Figure

Figure 17 Delinquent performance

LEAD TIME: 2 / ORDER QUANTITY: 25	CONTROL BALANCE	PERIOD								
ALLOCATED	1	3	4	5	6	7	8	9	10	
REQUIREMENTS	1		10	13		20	4			
SCHEDULED RECEIPTS		20								
ON HAND	3	22	12	–1	–1	–21	–25	–25	–25	
PLANNED ORDER RELEASES	25	25								

Figure 18 Premature or excessive performance

LEAD TIME: 2 / ORDER QUANTITY: 25	CONTROL BALANCE	PERIOD								
ALLOCATED		2	3	4	5	6	7	8	9	
REQUIREMENTS	– 1			10	13		20	4		
SCHEDULED RECEIPTS	–20			40						
ON HAND	21	21	21	51	38	38	18	14	14	
PLANNED ORDER RELEASES	–15									

–40

13, 3 units had been consumed, 20 units (prematurely) received, and 40 units placed on order during period 2, the record would appear as in Figure 18.

The control balances represent *deviations from plan* that can be printed out, at the end of each period, in the form of a special performance control report used for purposes of follow-up and corrective action. Such reports can easily be generated as a by-product of a net change MRP system. A regenerative MRP system, by its very nature, is unequipped to yield this type of management information.

requirements alteration

A special feature of some regenerative programs called *requirements alteration* is sometimes confused with net change. Requirements alteration is offered as an option in the PICS program products.[9]

Requirements alteration, an alternate program, is designed to process intervening changes in the master production schedule, between the regular requirements planning runs. The purpose here is to avoid complete schedule regeneration or full explosion. Input to the system are the new values (new bucket contents) in the master production schedule for the respective end items, rather than net changes from the previous status of this schedule. The system then carries out a *partial regeneration* of requirements, limiting the explosion to the changed end items and their components.

Requirements alteration is designed to respond only to changes in the master production schedule, and not to transaction-caused changes in lower-level item status. It is intended as an intra-cycle program to be followed by a regular requirements regeneration. Because requirements alteration updates the status (in its broader sense) of only those lower-level items affected by a given change in the master production schedule, the status of the rest continues deteriorating, as pointed out earlier. If the MRP system is to keep from degenerating, it must not be operated in a constant requirements alteration mode. (An exception to this rule would be the use of the requirements alteration program to reprocess the unchanged portion—normally the bulk—of the master production schedule at regular regeneration time.)

modes of net change use

A net change MRP system can be implemented for either of two modes of use:

- High frequency replanning (on, typically, a daily batch basis)
- Continuous, or online, replanning

Prevailing current practice, in manufacturing companies that have implemented net change systems, is daily batch for transaction processing (and consequently, replanning), with continuous online inquiry into the inventory item file. Under this approach, transactions are accumulated throughout the day and are sorted prior to the updating run. For reasons of data processing efficiency, other sequential processing techniques may be used, including low-level coding. The transaction processing run updates the respective inventory item records and carries out partial explosions, as required to maintain inter-level equilibrium.

Aside from current practice, however, the system's design allows it to become online transaction-driven whenever the user deems this mode desirable. Online transaction entry is a matter of terminal and software arrangements external to the logic of the net change MRP system proper, which is independent of these arrangements. 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.

A net change MRP system lends itself quite naturally to being operated in a continuous replanning mode because of its ability to fully process a single transaction at the time of its (random) entry. Net change MRP can function as an online program as soon as the other, technical conditions for online operation are met. Transactions will then be processed in a random stream, with partial explosions taking place as required. In this environ-

Table 1 Characteristics of MRP systems

	Regenerative	*Net change*
Master production schedule		
Viewed as	Consecutive issues	Continuum
Input to MRP system	Entire contents	Net difference from previous status
Explosion	Full, periodic	Partial, continuous
Requirements data		
Logically integral to item record	No	Yes
Up-to-date maintenance	No	Yes
Method of generation	Reconstituted	Modified, updated
Item inventory status		
File update	Limited to inventory data	Includes inventory and requirements data
Status in narrower sense	Maintained continuously	Not separately maintained
Status in broader sense	Reestablished periodically	Maintained continuously
Records in balance	Only at explosion time	At all times
Inter-level equilibrium		
Establishment	Reestablished only at explosion time	Maintained continuously
Effect of transaction entry	Only updates record directly affected	Transaction-triggered partial explosions
Logical requirement for allocation	No	Yes
Operating phases		
Requirements planning	Periodic, long intervals	No distinction
File updating	Intra-cycle, short intervals	No distinction
Performance control reporting	No	Yes

ment, low-level coding, as well as other batch processing techniques have no utility.

The essential distinguishing characteristics of regenerative versus net chang MRP systems are summarized in Table 1.

Evaluating net change MRP

In comparison with regenerative material requirements planning, the net change approach is superior in several respects. It enables the system to:

- Minimize the requirements planning job at schedule release time
- Process schedule changes occurring between releases as a matter of course, without need for special (requirements alteration) programming
- Be independent of the timing of both releases and changes
- Be continually up-to-date
- Generate non-delay outputs, thus communicating the need for user action at the earliest time possible

From the user's point of view, the most valuable feature of a net change system is its *reactiveness* – its unique capability of timely response to change.

Negative aspects of net change MRP, and the usual targets of skepticism can be categorized as follows:

- Reduced self-purging capability, and the consequent need for stricter disciplines in external operating procedure
- The relative processing inefficiency of a net change program
- The hypersensitivity of a net change system

reduced self-purging

From a practical point of view, the need for stricter discipline on the part of the user is indeed a disadvantage. With the conventional regenerative system, the old requirements plan is literally thrown away every time a new version (or, for that matter, the old version) of the master production schedule is processed. The job of exploding and planning requirements then proceeds from scratch. This has the advantage of throwing away certain old errors, plus data that became invalid due to change, along with the old plan. The self-purging effect is confined to requirements data (versus inventory data), as defined previously.

With the net change approach, the old plan is retained and merely modified, updated, so that old errors remain in the system. 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 plan (forecast) at the highest assembly level that is reflected in the system (master production schedule level) must be conscientiously reconciled with actual past requirements. Otherwise the discrepancies between quantities *planned* and *actual* are carried forward and their cumulative effect will gradually render the system ineffective.

Net change MRP is conceived as a continuous system that must be continuously maintained. It presupposes that high data integrity can be sustained, in both transaction reporting and file maintenance. 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 accumulates too many errors. The stand-by program is then run once, to purge the system by regenerating all requirements data. In actual practice, operational net change systems are being thus purged once or twice per year.[13]

processing inefficiency

As to the criticism of data processing inefficiency, it is a fact that net change is less efficient, and therefore more costly, primarily due to multiple access to inventory records in transaction posting, as well as in exploding requirements.

But this cannot be considered a valid argument against net change because any data processing method that does not utilize batch processing techniques is, by definition, relatively inefficient. In net change material requirements planning, the emphasis is on inventory management efficiency, not on data processing efficiency. In the development of MRP systems 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, the objective of data processing efficiency should be subordinated to the larger goal: improving the effectiveness of the business.

hypersensitivity

The most interesting of the criticisms directed at net change material requirements planning concerns the system's "hypersensitivity". Since file updating, under the net change approach, is equivalent to replanning, it may appear that the system calls for continual revision of user action taken previously. This is of concern especially where due dates of open purchase orders are involved, because it is not practical to subject these due dates to constant revision.

This type of criticism neglects to draw a distinction between the system being informed, up to the minute, and the frequency of action taken on the basis of the information. The latter can be decided upon (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 critic of a "hypersensitive" system argues, in effect, that it is better for an inventory management system to be out-of-date. Such an argument is unacceptable. The "hypersensitivity" on the level of planning is a virtue, not a drawback, of a net change MRP system. Hypersensitivity on the level of reaction can, and should, be dampened.

Not every change in inventory status calls for reaction. 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.

Prompt reaction to changes in requirements or other elements of inventory status 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. Inventory status is not significantly affected by most of the updating entries, but certain transactions, such as unscheduled stock disbursements, scrap, physical inventory adjustments (short counts), and miscellaneous demand exceeding forecast, do cause rebalancing (replanning) of inventory status.

Many changes may occur in the same inventory record on the same day, in which case the timing of open orders would have to be revised several times that day, even though the changes may have a mutually canceling effect. The user's reaction to change can, however, 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 need not react to the continuous stream of individual changes, but can let them accumulate for some period of time.

action cycles

The system can provide output of action requests on a cyclical basis. Some 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 is 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, a significant downward adjustment of on-hand inventory following a physical count, and so forth.

When major changes in the master production schedule are being processed or following regular periodic issues of a new 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.

Planning cycles and action cycles are established on a more or less arbitrary basis. Delaying action on available informaton does dampen reaction to change, but delay obviously cannot be prolonged indefinitely. Under any action cycle, once delay is terminated, 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. A net change MRP system 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 MRP

The superiority of net change material requirements planning over the orthodox, regenerative approach manifests itself primarily on the practical level of use. The net change MRP system's capability of prompt replanning in response to change is invaluable not only for purposes of inventory management but also (and particularly so) for purposes of production control.

In most manufacturing environments the relative priorities of open shop orders tend to change continuously, at a rate exceeding the ability of any regenerative, batch-oriented MRP system to replan and to revise order due dates in time. Priority planning and replanning, a classic problem in production control, is now susceptible to complete solution. A net change MRP system, however, is the prerequisite to this solution.

On the technical level, the continuous online implementation 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 including those required for an online, communications-oriented, interactive inventory management system. The system's central architecture remains unaffected by any of these (external) arrangements, and by the technology of input/output devices used.[14]

Several daily-batch net change systems are currently operational in the manufacturing industry. The full potential of the net change approach, however, will only be realized with online implementations of the future.

HISTORICAL NOTE AND ACKNOWLEDGMENT

In 1961, at the J. I. Case Company tractor plant in Racine, Wisconsin, a project group under the author's 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), and a weekly performance control report. The system covered about 20,000 active part numbers, including 4,000 assemblies with up to seven assembly levels. Because there was no available IBM programming support for a material requirements planning application at that time, the J. I. Case programmer team wrote their own equivalent of the Bill of Material Processor, in addition to the application programs.

The development and programming effort took ten months following a two-month feasibility study. The project team expended approximately six man-years in the development and 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 material requirements planning application. The system was subsequently reimplemented on an IBM 1410 System with an IBM 1301 disk file unit, and still later converted to an IBM System/360 Model 50.

The author's closest collaborators on the project were: A. R. Brani (Case), J. A. Chobanian (Case), H. D. Jones (Case), T. L. Musial (IBM), and E. F. Roeseler (Case). Company affiliations are as of that time. The author held overall responsibility for the system in his capacity, at that time, of Director of Production Control for the J. I. Case Company.

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