A Combinatory Approach to Order Release and Shop Scheduling in Discrete Manufacturing Environments

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Abstract

This paper presents a new approach for integrating materials requirements planning (MRP) and shop floor scheduling in discrete manufacturing environments. A dynamic finite capacity scheduling method interacts with a reverse MRP logic resulting in a production planning and control tool for simultaneous detailed scheduling and material planning. The proposed method, referred to as reverse MRP, overcomes a series of shortcomings related to the traditional MRP approach by considering capacity constrains, lead times fluctuations, lot sizing and priority control in a bucketless environment. Performance of the reverse MRP method, when studied through a set of simulation experiments in a typical textile industry, has been found to outperform the standard MRP system in terms of a number of scheduling and inventory performance indicators.

1. Introduction

The use of MRP, MRPII and ERP as a production planning system in manufacturing enterprises is based on the classic MRP methodology [1]. These information systems represent major investments and involve extensive efforts and organizational changes in companies that decide to employ them. Despite the vast and increasing adoption of such MRP-based systems [2], a growing number of authors criticize their poor performance in relation to implementation costs. Recent research, as in [3], [4] and [5], showed that few manufacturers were able to implement MRP-based systems successfully and many installations may be regarded as failures. While accurate percentages of unsuccessful implementations vary from study to study, each demonstrates a high failure rate ranging from 50 to 70 per cent. Moreover, only a small percentage will finally achieve a Class A MRP operation [6]. Reasons of MRP failure are commonly associated to the fact that MRP systems assume infinite production capacity, thus using inflated and constant lead times and do not produce detailed schedules for the shop floor, since MRP systems merely specify the job release and completion dates in the context of time buckets [7]. An extended review on MRP related problems in the production planning of manufacturing systems can be found in [8].

2. Literature review

A lot of research has been conducted in the past concerning the integration of capacity limitations into the MRP planning process. The majority of the less recently published models and algorithms on capacity-sensitive production planning are complex and difficult to use in practice. They employ either complex mathematical programming, as in [9], [10] and [11], or queuing models in order to calculate workload-dependent planned lead times, as in [12] and [13]. Due to the fact that when the number of variables and constraints is raised computational time increases rapidly, they operate under a lot of simplistic assumptions restricting their use to small problems only. In addition, their performance under a dynamic production environment may be unreliable. As they are not easily understood by the planner, confidence in the results of these systems is reduced [14].

These limitations have led to a lot of recently published research on the performance of different finite-capacitated production planning systems under MRP planning and control rules. Agrawal et al. [15] studied production planning in manufacturing facilities that produce large and complex assemblies, for which cycle times range between two months to two years. Their approach employs a lead-time evaluation and scheduling algorithm for performing backward scheduling of operations with the unique objective of minimizing cycle time. The estimated lead times are then scaled to account for capacity sharing effects by multiple products in common resources and are used by a MRP-based system to release work-orders to the shop floor. Numerical experiments showed that cycle time

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improved but still capacity was roughly planned based on estimated lead time offsets, a fixed lot-size for each end item and an average product mix obtained from historical data and forecasts.

Crauwels and Oudheusden [16] proposed a method for transforming planned MRP orders into a detailed schedule, in a single machine environment, by employing a set of simple heuristic rules. Rough family specific setup times were used. The planning horizon was still segmented into time buckets as in conventional MRP. The end times of these periods roughly constituted the different job due dates.

Ho and Chang [8] proposed an integrated MRP and Just-In-Time (JIT) framework, modeled as an integer linear program in combination with forward and backward heuristics for finding detailed shop floor schedules with the objective of minimizing total production cost, without, however, providing any information related to actual implementations. They also used a time bucketed planning horizon under the limitation that no consecutive operations of a part can be scheduled in the same period.

Jin and Thomson [17] developed a new MRP-based framework that is capable of addressing engineered-to-order environments. This framework incorporates a capacity scheduling module able to produce schedules on an aggregate level, utilizing partially defined BOMs and process plans in order to react to design changes. No relevant pilot cases are reported.

In another study, Koh et al. [2] presented the development and implementation of a generic model for simulating MRP-controlled finite capacitated manufacturing environments in order to study the effects of uncertainty and production fluctuations on a company's performance. Results showed less late deliveries in relation to traditional incapacitated MRP.

Nagendra et al. [18] focused on a method for scheduling and sequencing production orders from MRP schedules in order to reduce the total time spent on setups and minimize the inventory of finished parts. Their model consists of four heuristic algorithms that are solved sequentially. The presented method is illustrated by a general example together with a comparison with a lot-for-lot MRP implementation. The system operates within the constraints imposed by the infinite capacity MRP input. Results from real case studies are not reported.

Pandey et al. [14] presented a capacitated material requirements planning algorithm that has been found to be superior to the existing MRP system in terms of mean job tardiness and inventory holding cost per part. However, these results are obtained through a simplified example, the lot-sizing problem is not addressed and only a single resource for each part type is assumed to be available.

Rom et al. [19] studied a model to solve capacity constraints based on resource constrained project scheduling concepts. This model addresses capacity and material requirements planning in a job shop environment. The efficacy of this approach was tested on MRP systems by comparing the inventory carrying costs and resource allocation of its solutions to those obtained by using a traditional MRP model. Improved schedules with considerable reductions in inventory carrying costs are reported.

Tempelmeier [20] developed a resource-constrained approach to lot-sizing that cooperates with standard production and control systems like the typical MRP. In his approach the item-by-item lot size planning is substituted by the heuristic solution of a multi-level, multi-item dynamic capacitated lot sizing problem using setup times for general product structures. The author focuses exclusively on the lot size planning stage and on a possible integration with a standard MRP-based software system.

3. The reverse MRP method

Literature on capacity-sensitive MRP systems fails to provide a comprehensive solution to all discrete manufacturing environments. Their application is usually limited to a number of constraints, such as the number of machines and processing stages, bucketed planning horizon convention etc. Most researchers developed capacity sensitive models that require input from an interfaced infinite capacitated MRP system. This paper addresses the implementation of the reverse MRP (r-MRP) method, for integrated production scheduling and material planning, in textiles. The r-MRP methodology is not MRP-based and it supports the integration of shop floor scheduling and material planning under the constraints imposed by the finite capacity of a manufacturing system.

The new approach can be implemented in discrete multi-stage and multi-product manufacturing industries with multiple parallel machines at each stage. Final or semi-final products can have linear or divergent structures with multi-level components. Alternative resources can be used to perform the same operation considering their specific quality, productivity, setup and processing costs per time unit. Setup time in every resource is sequence dependent. Each final product must follow the precedence relationships within its routing. The direct inputs and outputs of r-MRP processing are shown in figure 1.

The r-MRP method needs to be up-to-date regarding the exact inventory status of every item it controls before it plans order releases for each one of them. Information about projected on hand quantities, scheduled order releases and receipts is stored in a file named Inventory Record (IR) or Item Master File. These data along with the shop floor schedule reveal the net requirements for each item. Changes due to stock receipts, changed orders, stock withdrawals, scrap, corrections imposed by

cycle counting and similar events are also recorded into this file.

Apart from the dynamic data that are stored and regularly updated, the IR module also contains static data that describe every item uniquely. These data are important in purchasing, cost accounting and other functions of a firm and include: part name, code/number, low-level code, unit of measure, supply lead time for raw materials, lot-sizing technique, safety stock, safety lead time, standard ordering cost, carrying cost per period, lot-sizing adjustment factors and linkage to the compact BOM module, that is the second basic input to r-MRP.

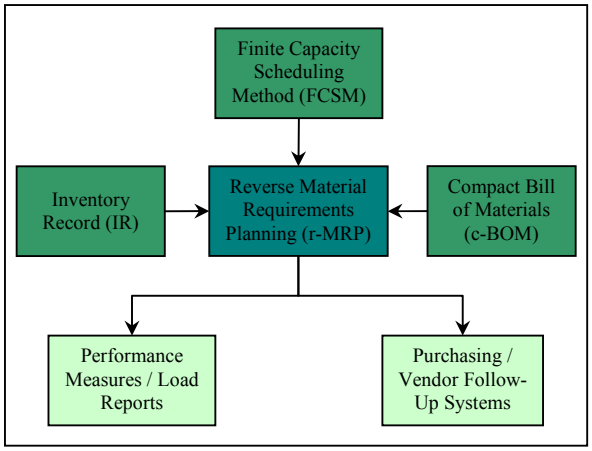


Figure 1. Basic structure of the r-MRP method

The function of the compact Bill of Materials (c-BOM) module is critical to the integration of material planning and shop scheduling within the r-MRP method. A simple BOM contains a listing of the assemblies, subassemblies, components and raw materials that are required to produce one unit of a finished product. A routing describes the sequence of the operations required and the corresponding workcenters to perform them. The attributes of the routing file also include setup and run time for each operation and the appropriate alternative resources that can perform them, as they are derived from Process Planning [1].

The compact BOM combines both BOM and routing data in a single file, associating components and raw materials to the operation that requires them in the routing sequence. Thus, all the parents of a material are operations and vice versa. The construction of c-BOM is appropriate for estimating Work-In-Process (WIP) inventory as well as for cost accounting purposes regarding end products. The most important function of c-BOM is that it facilitates the integration of material and capacity planning within the shop floor schedule.

The c-BOM module is setup by combining single level compact BOMs in a matrix form. The latter is in fact a where-used summarized list, where all items are listed along with the corresponding quantities or fractions with which they participate in their parent operations. Requirements for common items used by several parents or multi-level items that appear on different levels in one or more c-BOMs are accumulated in continuous time from every scheduled parent operation in the shop floor schedule. Net requirements and planned orders are calculated when the level-by-level finite capacity scheduling method has reached the lowest level in which they appear (low-level coding). Moreover, expensive tooling or chemicals consumable during materials processing are also included in a c-BOM. The r-MRP method plans replenishment orders for them, as for any other item, based on their inventory records and the shop floor schedule, as derived by the FCSM module that is the third basic input to r-MRP.

Orders released to the shop floor are directed to a dynamic Finite Capacity Scheduling Method (FCSM) in order to allocate their operations to specific resources, producing the entire Shop Floor Schedule (SFS). This method creates a hierarchical model of both the production facility and the workload and operates under discrete event simulation. The production facility is divided into Job Shops that can produce a family of similar semi-final and end products. Each Job Shop is further divided into Workcenters, which in turn consist of a number of Resources. The latter can be defined as individual production cells or parallel processors that can perform similar operations. The workload's hierarchy corresponds to the facility's hierarchy. Orders are broken down into Jobs, which in turn consist of a number of Tasks. An Order corresponds to the overall production facility and is divided into Jobs that based on their specifications, can only be processed by a suitable Job Shop. A Job consists of Tasks that can be released to one Workcenter only. Tasks can be dispatched to more than one of the Workcenter's Resources. The dispatching logic behind the assignment of a Task to a specific Resource can be either a multiple-criteria decision making technique [21], or a simple dispatching rule. The constraints taken into consideration in releasing and dispatching Jobs and Tasks include the facility's finite capacity and their precedence relationships, as recorded in the c-BOM files.

When the multiple-criteria decision making technique is used, several alternatives are formed and evaluated before assigning the available resources to pending production tasks. The choice of the best alternative is made by evaluating a set of criteria, such as cost, flowtime, quality and tardiness, in a decision matrix. A utility function is applied to rank the alternatives and choose the best. Released orders are scheduled directly, without aggregation. Grouping for the sake of machine efficiency or economical lot size is handled by assigning proper weight factors to the relevant criteria, not by aggregating them into one order.

The FCSM was specially adjusted for r-MRP in order to be able to schedule both forward and backward. Forward FCSM will schedule all tasks of a job from the

schedule start date starting with the first task. It aims at completing each job as early as possible. It can also be used to find out whether the earliest feasible completion time will meet customer's requirements. Backward FCSM will schedule all tasks of a job from its due dates, starting from the last task. Its objective is to complete each job on or close to its due date, thus minimizing its slack time.

Schedules are constructed on the basis of events occurring sequentially through time. The next scheduling decision is identified by moving along the time horizon until an event is scheduled to occur that will initiate a change in the status of the system. This would usually be the completion of an operation on one of the machines, or the arrival of a job to one of the machine queues. All operations eligible for loading at the time a machine becomes available are considered. When there are multiple jobs competing for a machine, the selected operational policy is used to determine the highest priority operation. Hence the schedule is constructed by simulating the behavior of the shop through real calendar time.

In every case, since the produced SFS is based on a finite capacity scheduling method, r-MRP's capacity and material plans will be feasible, without the need to perform loops like those often encountered in MRP II systems between MPS, MRP and CRP. As soon as the FCSM forms the SFS, the r-MRP method produces the materials plan by relating every scheduled operation to the corresponding materials in the c-BOM module. Requirements are accumulated in continuous time from every scheduled parent operation in the shop floor schedule and netted using IR's data (Figure 1).

In order to group them and determine an order's lot size, a lot-sizing technique built-in the r-MRP method, referred as Least Cumulative Cost (LCC), is employed. In order to support the continuous time function of r-MRP, it allows both lot sizes and order time intervals to vary. The LCC technique is based on the premise that the sum of setup (for manufactured items) or ordering (for purchased items) cost and inventory carrying cost will be minimized when their values are nearly equal. The LCC technique involves a series of iterations, comparing ordering and carrying costs for a succession of increasingly larger lots. The exact lot size is computed and adjusted by taking into consideration a number of constraints and parameters, such as safety stock, minimum and maximum batch sizes, shrinkage factors and lot size adjustments due to process equipment considerations [7].

4. Implementation of reverse MRP method

Reverse MRP was implemented in a software tool using Visual C++, version 5.0, for discrete event simulation and Visual Basic Applications coding (VBA), version 6.0, for order release. The integration is achieved through an appropriately developed Open Database Connectivity driver (ODBC).

Performance of the r-MRP methodology was studied through a set of simulation experiments in a vertically organized Greek textile industry. The under study enterprise operates in the woollen textile system and its product range includes yarns for clothing, carpeting, knitting and wool/synthetic carpets. The proposed r-MRP method has been applied to the production line of blend carpets. The selected production line consists of three discrete departments, namely Dyeing, Spinning and Weaving department. Each of them has been modelled as a Job Shop. The hierarchical facility model breakdown of the selected production line and the tasks associated with each workcenter, are listed in the following table.

Job Shops	Workcenter ID	Task Description	Resources
Dyeing	DYE-WC	Dyeing	1
	PRESS-WC	Hydroextraction	1
	DRY-WC	Drying	1
Spinning	PREP-WC	Opening	2
	BLEND-WC	Blending	6
	CARD-WC	Carding	3
	SPIN-WC	Spinning	7
	VAPOR-WC	Vaporizing	2
	WIND-WC	Cleaning	3
	SPOOL-WC	Spooling	4
Weaving	WEAV-WC	Weaving	27
3 Job Shops	**11 Workcenters**		**57 Resources**

Table 1. Hierarchical facility model

The first processing stage in the production line of blend carpets is the dyeing of the required quantities of raw materials (fibre mass) in the appropriate colours. This operation is performed in the Dyeing job shop. The second stage is the spinning of the required quantities of yarn types in the Spinning job shop. Finally, the third processing stage is the weaving that is performed in the Weaving job shop. The tasks performed in each job shop are sequentially listed in table 1. However, depending on the yarn type, the exact material flow may vary in the Spinning job shop.

The main point of interest lies within the production planning of the spinning and weaving job shops that contain a large number of alternative resources capable of performing the same task. The workload model for the selected production area consists of more than 200 different job types for the weaving job shop and 60 job types for the spinning job shop. Each job type in the weaving job shop corresponds to a single carpet type, as defined by its colour set, quality (surface density), shape and dimensions. Each job type in the spinning job shop corresponds to a single yarn type defined by its composition, quality (type of fibres selected), colour and title. The tasks comprising these jobs are shown in table 1, next to their corresponding workcenters. Their individual precedence relationships, the processing and

setup times required by each alternative resource are all stored in the compact BOM module.

Both forward and backward FCSM can be utilized for the detailed assignment of these tasks to their suitable resources. The choice depends mainly on the specific characteristics and policy of the production system. Forward FCSM can be applied to rush jobs and backward FCSM can be applied to expensive, high inventory value or long due date jobs. In an assembly manufacturing system the scheduling objective of minimizing the cumulative lead time for a set of assembled jobs can be achieved by applying backward FCSM to components jobs after the schedule start date of the final assembly job is determined by either forward or backward FCSM. Component jobs required for making a multi-stage product should be finished at the same time and assembled together to achieve a no slack time, minimise WIP and cumulative lead time. Weaving, the unique task of a weaving job, can be considered as an assembly operation of four different yarn systems, namely the warp, weft, pile and selvage yarn system, that must be available together to begin execution of an order in the weaving workcenter. So tasks in the spinning job shop to produce them are scheduled backwards from the time they are required in the weaving job shop.

The relative performance of 11 different assignment policies for the same workload was evaluated through a set of both scheduling and material planning performance indicators. Mean tardiness, mean flowtime, mean queue and mean reserve time were used as performance indicators for evaluating the obtained detailed shop floor schedules. Mean inventory cost, mean inventory level and customer service level were used as performance indicators for evaluating the material plans.

5. Results and discussion

A set of simulation experiments have been conducted in order to validate the efficiency of r-MRP. Real data were collected from the sales department of the under study textile industry, covering a planning horizon of 60 days, plus 30 days' data for initialisation purposes. In all different scenarios 160 weaving job orders and 120 spinning job orders were scheduled using the FCSM module, resulting into more than 1800 tasks assigned to 54 resources in every simulation run. The 11 different assignment logics that were employed resulted into more than 17600 task assignments. The weaving job shop was scheduled using backward FCSM and the results were used as input to the scheduling of the spinning job shop. Due to the assembly nature of the weaving operation, backwards FCSM version was also used for the scheduling of the spinning job shop. Well-known conventional dispatching rules and a multiple-criteria decision making technique [21] were used as the assignment logic for the same workload. The production facility operates two shifts a day, six days a week. The mean capacity utilization level was kept constant at 70% in all experimental simulations.

The setting of orders' due dates can be the result of delivery times promised to customers, MRP processing or managerial decisions based on various due date setting policies, as in [22], [23]. In this study, job due dates (DD_j) were calculated using the number of operations rule (NOP), as follows:

$$DD_j = AD_j + k \cdot N_j$$

Where: AD_j is the arrival date and time of job j, k is the allowance factor in days and N_j is the number of tasks of job j. Since time in queue is usually the largest component of a job's lead time, the number of tasks it contains can be used as an indicator of the required flowtime. The value of k was set at 0.9. This configuration results in a set of relatively tight due dates. The selection of such a tight condition was based on the premise that the relative performance of different operational policies can be depicted more clearly in tight due date environments. Moreover, tight due dates can provide a competitive advantage by permitting the firm to offer an improved level of customer service, as well as achieve lower costs through reductions in WIP inventory. Results in terms of the scheduling performance indicators and the customer service level are shown in the two figures hereafter.

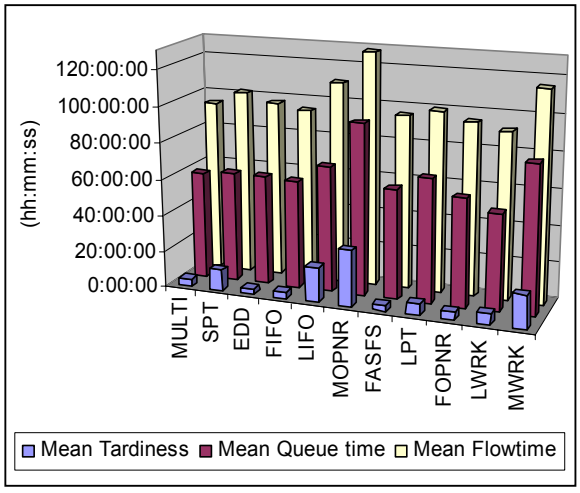


Figure 2. Mean tardiness, flow and queue time in different experimental scenarios

The multi-criteria decision making technique (MULTI) and the LWRK dispatching rule produced the best results in shop floor scheduling performance, in terms of mean tardiness, mean queue and flow time (Figure 2). As it was expected, the LIFO, MOPNR and MWRK rules performed poorly with respect to these measures. Moreover, time in queue accounted for a large part of an order's total lead time in all experimental scenarios.

Reserve time is defined as the time difference between an order's arrival time and its actual start time. It can be utilized as an indicator of a schedule's flexibility, or else its ability to reserve capacity in the near term in order to be able to respond more efficiently in new customer demands or rush orders. High mean reserve times also correspond to low WIP inventories. This is a basic advantage of using backward FCSM due to the fact that it attempts to minimize jobs' slack times and thus producing high reserve times. The MULTI and SPT policies were more effective in maximizing the mean reserve time, while the MOPNR, MWRK and LPT rules performed far more poorly than any other.

Generally, a relative high customer service level was achieved in all simulation experiments with the exception of the MOPNR, MWRK, EDD and LIFO rules, where service level fell below 80% (Figure 3). The reason is that these rules try to promote orders that are less likely to finish on time due to their number of operations, work remaining, early due date and late arrival, respectively. This logic can result in prioritizing orders that would anyway finish late at the expense of other others that would otherwise complete before their due date, thereby leading to even more late orders.

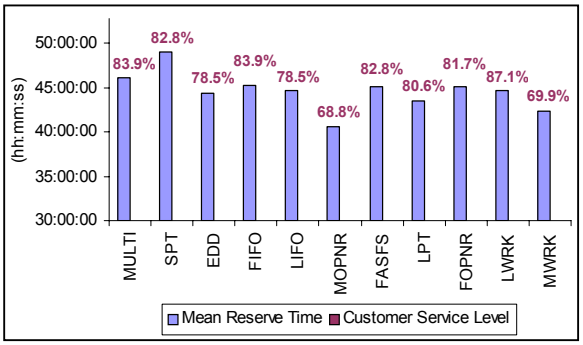


Figure 3. Mean reserve time and customer service level in different scenarios

For the most final products in this case study, the value added content of labor was less than the value added content of materials. Therefore, apart from labor standards and labor performance measures it was substantial to institute measures of inventory performance. The performance indicators that were used to assess the output material plans were the mean inventory cost and the mean inventory level. Comparisons were made between the proposed method and traditional MRP in all experiments. The built-in LCC lot-sizing technique was used for the case of r-MRP, while the most popular lot-sizing technique, that is lot-for-lot, was selected for the MRP system. The reason is that this technique minimizes inventory carrying costs in high inventory value environments. It also performs well for items with low setup costs. This was the case in the textile industry under study. It should be highlighted that the MRP method produced material plans from a risk neutral position due to the fact that orders released by the FCSM formed a feasible MPS from the start.

In both r-MRP and MRP experimental series it was assumed that inventory was stocked for the time between receipt and consumption in the shop floor schedule. The r-MRP method outperformed MRP in all scenarios concerning the mean inventory cost performance indicator (Figure 4). The multi-criteria decision making technique (MULTI) and the FASFS rule produced the best results for r-MRP. The only operational policy that performed sufficiently well along with classic MRP was MOPNR. The use of EDD and FOPNR heuristics along with MRP proved most disappointing. The exactly same relative performances were reproduced in the case of the mean inventory level performance indicator.

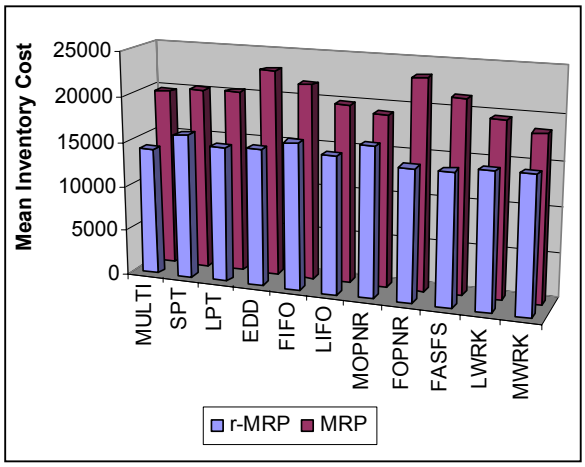


Figure 4. Mean inventory cost in different experimental scenarios

Reverse MRP outperformed classic MRP in all experimental scenarios concerning the material plans, in terms of both inventory cost and inventory level. This is mainly attributed to the fact that the r-MRP method provides the user with the exact timing that an order of an item is needed and capacity actually exists to process it. This reveals the main deficiency of classic MRP, which is the assumption of infinite capacity and constant lead times. Moreover, large economies can be achieved in case of high value items. The ability to group requirements more efficiently in r-MRP comparing to the conventional time buckets of MRP systems, leads to lower inventory holding and ordering costs.

To sum up the above results, in our case study, it was found that in order to simultaneously achieve an efficient shop floor schedule and a low cost material plan the r-MRP method should be used together with the multiple-criteria decision making technique as the operational policy of the FCSM module.

Next, a qualitative analysis will follow investigating how management's policy can affect a firm's inventory performance and how it reflects on the selection of the most effective production planning and control system.

While ordering costs for items can be estimated with high accuracy, carrying costs are usually a rough approximation and a mean to express management's policy in inventory investment. If management considers inventory items as waste, then increasing their estimated carrying cost per unit and per period (C_h) will result in smaller lot sizes, more frequent ordering and subsequently lower inventories. On the contrary if management expects inventory to yield economical results like any other capital investment, then it may decide to decrease carrying cost coefficients C_h in order to reach higher inventory levels.

The fact that carrying cost coefficients' values can be used to reflect management's objectives in inventory policy, revealed the need for a sensitivity analysis of the results of both MRP and r-MRP methods. For this purpose a 'management policy variable' was defined, referred as the carrying cost design factor (C_{df}), to test how material plans may be affected by using different inventory policies. In each experimental simulation different values of C_{df} were used to adjust the nominal values of carrying costs per unit and per period (C_h) for all r-MRP controlled items. The design factor C_{df} is expressed as a percentage of the nominal carrying cost coefficient C_h of each item. Thereby, C_{df} values above 100% correspond to higher C_h values for each item than the nominal and the opposite. The impact of C_{df} on mean inventory cost is shown in the following figure.

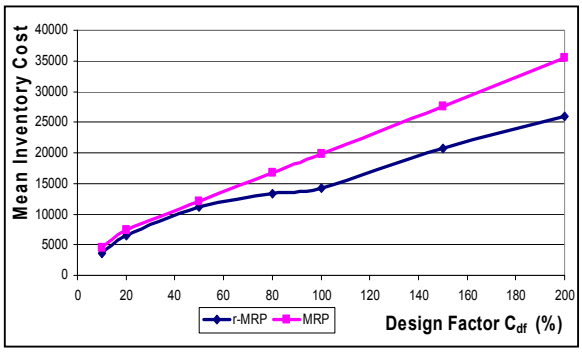


Figure 5. Mean inventory cost versus C_{df}

The operational policy used in all experimental simulations with varying C_{df} was the multiple-criteria decision making technique, while the lot-sizing method was again LCC for r-MRP and lot-for-lot for MRP. What is interesting to notice is that for C_{df} values lower than 60%, that is for reduced carrying costs than the nominal, the mean inventory cost performance of classic MRP converges with r-MRP results. This fact verifies the suggestion that for low inventory value items, classic MRP may sufficiently control their supplies. The maximum advantage from implementing r-MRP can be derived in firms with expensive inventory items and frequent small deliveries. For high C_{df} values, while inventory costs rise in both situations, performance of r-MRP is rapidly improving in relation to MRP. Therefore the use of C_{df} can reveal the limit that simple MRP is sufficient to control a specific item, beyond which it should pass under the control of the r-MRP approach.

6. Conclusions

Combinatory material planning and shop floor scheduling solves material and capacity constraints together. Reverse MRP is an integrated tool for simultaneous detailed scheduling and material planning. Both scheduling and inventory performance indicators were implemented to assist the selection of the best shop floor schedule and material plan combination. The proposed method is best suited for production planning and control of discrete manufacturing companies, especially for those characterized by batch production processes with high product and volume variety where production times are relatively short. In such cases the expected benefits include an efficient shop floor schedule, smoother flow of materials, lower WIP, reduced inventory holding costs and demand for storage space. The r-MRP method, by functioning dynamically in a continuous time scale, can also support frequent small deliveries of purchased materials in cases where their suppliers offer this option. This is consistent with JIT principles.

In contrast to MRP, which is rather a labour-efficient system, r-MRP is a material-efficient methodology. Early consideration of capacity means that lead time offsets are calculated dynamically based on actual loads scheduled in each workcenter, at the exact time they are needed. The generated plan is viable because the material requirements are synchronized with a finite capacity schedule. Although fluctuations may be observed when simulating the exact flow of orders in detail, it is quite likely that the results will be superior to those attributed to an infinite capacitated conventional MRP system. This was validated through the case study presented in this paper. It was also shown that for low inventory value items, classic MRP may effectively control their supplies.

If demand variation or a change in the shop floor occurs, the user of r-MRP can feed its database with the new data and produce an updated schedule and material plan. A number of schedule alternatives can be build that allow "what-if" analysis evaluating the impact of a change on existing scheduled jobs. To maintain constant visibility of how changes may affect an order, the shop floor schedule should be built with customer and forecast orders for as far out as possible. Rescheduling and updating shop floor schedule every day is important since decay in information validity grows as the schedule's planning horizon is lengthened. Since a simulation run for a planning horizon of several months takes only a few minutes, it is easy for the user any time that something unpredicted occurs, to reproduce

efficiently an updated plan for the entire production facility.

Directions for future work, in order to further validate the efficiency of the proposed approach, include evaluation of dampening strategies to confront 'nervousness' caused by uncertainty in demand or supply and rescheduling of open orders. The effect of the frozen horizon length on the shop floor schedule is another issue that should be investigated. Furthermore, special adaptations of the LCC lot-sizing technique are needed in case of deteriorating inventory and where quantity discounts are available or transportation savings are realized when shipping full carload lots.

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