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Production Planning and Control Systems-State of the Art and New Directions

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Abstract: This chapter begins with a description of the role of production planning and control (PPC) within the manufacturing function. After discussing the impact of the operating environment on the choice a system for PPC, we describe some recent empirical evidence regarding the use and performance results of various PPC systems. This is followed by a brief overview of the two most widely used systems for production planning and control. We then describe a recent development in the area of short-term detailed scheduling exploiting the latest developments in computing technology. The chapter concludes with a discussion of an emerging paradigm for exploiting the advancements in computing technology for developing sophisticated state-of-the-art PPC systems capable of satisfying the needs of tomorrow's market place.

1. Introduction

The Production Planning and Control system is a major component of the infrastructure which supports the manufacturing process selected for the specific environment faced by the firm [27]. Production planning and control (PPC) is a major function essential for the successful operation of every manufacturing company. It is a complex task because of the large data volume involved [18]. Villa [26] characterizes it as a control optimization problem for a large-scale dynamic system. He argues that the evolution of a PPC system is influenced largely by two types of events: (1) events to be planned and (2) events to be controlled.

A PPC system is mainly concerned with ensuring efficient and effective use of capacity for satisfying anticipated demand. Four major tasks comprise production planning and control: Aggregate Capacity Planning, Material Planning, Production Activity Planning, and Production Activity Control. Aggregate Capacity Planning focuses on matching demand and supply (i.e., capacity) over the short or medium horizon. Material Planning deals with making sure that the needed material is available at the right time. Production Activity Planning generates detailed plans ensuring that the available capacity is consumed in an effective and efficient fashion. Production activity control is concerned with execution of the plans.

Successful companies plan and control their operations using a formal system. Systems designed to support companies in planning and controlling their operations are called Production Planning and Control Systems. Many PPC systems are being used by companies around the world. Earlier this century firms often used what has come to be known as Reorder Point Systems (ROP). With the advent of computers,

during the early sixties, the use of Material Requirements Planning Systems became widespread. Beginning in the 1960's, many traditional reorder point systems were replaced by what are known as Manufacturing Resource Planning (MRP) systems. According to some estimates, more than 20,000 companies in various parts of the world deploy MRP systems to plan and control their operations. In the early 1980's the "MRP Crusade" ran up against the "JIT Crusade" built around the Kanban system. In the last decade, largely due to some Japanese firms operating under the Just-In-Time philosophy, Kanban-based systems became popular. At about the same time, another new system called Optimized Production Technology based upon the "drum-buffer-rope" approach [5] was introduced and is used by some companies. Thus, the four most common PPC systems used in practice and discussed in the literature are the following: MRP-based push systems (MRP), Kanban-based pull systems (Kanban), constraint theory based systems that identify and schedule according to bottleneck resources (OPT), and traditional reorder point based systems (ROP).

Computer integrated manufacturing (CIM) links all vital functions of a manufacturing organization through an integrated computer system thus providing the capability to consistently produce the desired products at a low cost and high quality, and in a timely fashion. The CIM concept spans the entire firm. For the purposes of this chapter we limit attention to only the planning and control function. Within CIM, the PPC system is computerized. CIM requires that the PPC system be tightly integrated and be capable of speed and sophistication. This is so because of the increased product variety typically associated with a CIM environment. Furthermore, the enhanced capability to supply products at short notice (reduced customer leadtimes), the need for accurate planning of capacity and materials, and tighter control of the shop floor activities in greatly increased. In short, under CIM the PPC system plays a more central and important role in ensuring effectiveness and efficiency.

2. Manufacturing Environment and PPC Systems

Recent market-trends indicate that manufacturing firms are being required to excel in a variety of dimensions [6]. Low cost manufacturing, quicker product development, faster delivery, wider variety of products, wider range of efficient production volumes, and steadily increasing quality standards have all become important. Demand for capabilities that would have been impossible to meet under the more dichotomous strategies of the not too distant past have become the norm for competition in today's manufacturing environment [2, 25, 28].

The environmental conditions faced by the manufacturing function can be characterized by (1) product volume and variety, (2) competitive priorities, and (3) process technologies and infrastructure available within the firm. The volatility of demand, the level of product design changes, and the rate of new product introduction define the product volume and variety mix. In terms of competitive priorities, firms are faced with the need for holding the line on costs while meeting demand for more frequent and smaller lot deliveries of an increasing variety of products. The process technology available within the firm (e.g., Numerically Controlled Machines, Flexible

Manufacturing Systems, etc.) determines its flexibility and ability to support the competitive priorities.

Given the multidimensional strategic objectives of manufacturing firms and the increasingly complex environments within which they operate, the selection and implementation of a suitable PPC system is an important concern for manufacturing firms worldwide. Consequently, many managers are concerned with the fit between their infrastructure support system and manufacturing environment [22]. However, historically, the selection of PPC systems has been influenced more by the latest system developments, internal knowledge, and information processing constraints of the firm than by environmental factors faced by the firm. Some might argue that a PPC system does not in itself add value. A good fit between the manufacturing environment and PPC system, however, can facilitate better execution of activities that add value. Others might argue that the choice of PPC system is simple since the systems are mutually exclusive in terms of the environments they fit. However, manufacturing environmental factors such as differences in complexity, information processing burden, implementation discipline requirements, perspective (local Vs global) or focus of operation (top down Vs bottom up) make one system more attractive than another. Clearly, when demand is both stable and predictable there is very little need for a sophisticated system for production planning and control. It is when faced with a highly unstable or a highly unpredictable demand that choosing the right kind of PPC system becomes crucial for achieving both effectiveness and efficiency.

For example, one could probably make a strong case for selecting a system such as MRP to support a functionally laid out process that produces (in batches) a large variety of products, that are in different stages of their product life cycle. Given the associated volume fluctuations and the necessity for frequent design changes, MRP provides sufficient planning and replanning ability to accommodate the dynamic nature of such an environment. In general, MRP based push systems are likely to perform well in a complex environment and in the presence of high demand variability as long as the predictability of demand is high. Its performance may deteriorate rapidly as demand uncertainty is increased (i.e., predictability decreases).

On the other hand, products further along their product life cycle may have consistently higher volume with minimal design changes. For example, consider a firm producing a small variety of products using a product layout. Under these more stable conditions, a simple information system such as Kanban may well serve the process more effectively. Overall, pull systems, such as Kanban, may work well when the demand variability is low. The level of uncertainty in demand (i.e., not knowing when the next Kanban card will arrive) may not be as critical to system performance. Thus, pull systems may not be as sensitive to predictability of demand as, for example, push systems are likely to be. When the demand is highly unpredictable and demand variability is also high, systems such as OPT are likely to produce superior results.

Based on such considerations, for each process type we superimpose a PPC system that might represent the "best" for the conditions that define the firm's environment. Table 1, taken from Newman and Sridharan [17], presents a mapping of the four types of PPC systems commonly found in use in terms of the environments in which they are likely to perform well. However, the empirical validation of such a taxonomy may be cloudy. While a good fit between the PPC system and the firm's

environment may be necessary, it alone may not be sufficient to assure success. For example, consider a firm producing a wide range of custom products in small batches using a make-to-order policy. While MRP may seem like a logical choice, performance may be clouded by the use of dedicated process technologies or overly centralized decision making. Alternatively, a similar firm producing the same product mix with general purpose technologies may still find performance below expectations if competitive priorities are based upon price and delivery speed.

Demand Predictability	Demand Variability Low High	
Low	Kanban	OPT
High	All	MRP

Table 1. PPC Systems Suitable for a Given Environment

Clearly, in a stable and predictable environment there is very little need for a complex and sophisticated planning and control system. In such cases a simple PPC system such as ROP may provide acceptable performance. However, when the environment is not stable the planning and control system should be able to cope with the volatility and thus become very important. Under such conditions, a simple system like ROP is often inadequate. When the production process is streamlined and simple, it is often flexible and, thus, is able to handle much of the uncertainty in demand. In such cases Kanban systems are the most effective. A complex production system facing an unstable environment needs a sophisticated planning and control system such as MRP or OPT. When demand is not stable, i.e., it is highly fluctuating, but largely predictable, MRP systems may be the appropriate choice. MRP systems are particularly well suited for firms facing an environment where the process is complex (i.e., product variety is large, production process is batch oriented, and demand is dynamic). When demand is unpredictable but is steady, and the production process is simple, Kanban systems appear to be the best choice. Finally, OPT based systems appear to be best equipped to handle the case of highly variable and unpredictable demand. Granted that external predictability of demand is, at least in some sense, a function of forecasting, yet a great deal of internal demand predictability is a function of internal stability. However, variability of demand is external to the firm and is often not fully controllable.

3. Performance of Existing PPC Systems

A recent survey of companies covering a wide spectrum of manufacturing industries ranging from machine tools, automobile components, furniture, plastics, and medical equipment to computers and defense electronics provides some indication regarding the effectiveness of the four traditional PPC systems [16, 17]. The results show that, of the four PPC systems described above, MRP system was found to be the most widely used system (56%). This is followed by ROP based systems (22%), Kanban (8%), and OPT based systems (5%). Roughly 9% of the firms reported using some "in-house" system (categorized as "other") created to meet their unique needs.

The results indicate that MRP based systems appear to be used in firms belonging to each of the three different process types (job shops, repetitive, and process) and across all size firms. ROP based systems were implemented mainly in smaller firms and were evenly divided between process and job shop situations. Most Kanban implementations were also found in smaller shops. OPT users, on the other hand, appear to be concentrated in larger process industries. Table 2 provides a summary of the survey results in terms of the distribution of firm performance within each PPC system user group.

	Percentage of respondents using			
	MRP	Kanban	OPT	ROP
Inventory Turns				
> 100	5.45	0.00	16.67	0.00
10 - 100	20.00	9.09	16.67	30.77
5 - 10	56.36	54.55	16.67	53.85
< 5	18.18	36.36	50.00	15.38
On-Time Delivery (%)				
> 95	27.27	27.27	50.00	50.00
90 - 95	16.36	18.18	0.00	19.23
80 - 90	30.91	54.55	33.33	15.38
< 80	25.45	0.00	16.67	15.38
Lead Time (Weeks)				
< 2	14.55	18.18	16.67	46.15
2 - 5	27.27	18.18	16.67	15.38
5 - 10	30.91	36.36	16.67	23.08
10 - 15	14.55	9.09	16.67	7.69
> 15	12.73	18.18	33.33	7.69
Lateness (Weeks)				
< 1	41.82	36.36	33.33	65.38
1 - 2	38.18	36.36	50.00	23.08
2 - 5	16.36	9.09	0.00	7.69
> 5	3.64	18.18	16.67	3.85
Utilization (%)				
> 95	3.64	18.18	33.33	19.23
90 - 95	16.36	18.18	16.67	15.38
80 - 90	25.45	27.27	33.33	23.08
< 80	54.55	36.36	16.67	42.31

Table 2. Performance Distributions

These results provide some valuable insights into the relative performance of alternative PPC systems. Based on the results, it appears that MRP systems are most

versatile and are able to cope with increased complexity. The increased information processing requirements entailed by MRP systems, however, may prove to be a hindrance for firms that do not need a complex system (i.e. where product variety is low and demand is steady). Under such cases the use of ROP systems may be appropriate. ROP systems are cheaper to implement and are simpler compared to MRP systems. They, however, are inferior in handling situations where demand is unsteady and product variety is high. Kanban and OPT systems are used by so few firms and under restrictive conditions that it is difficult to interpret the results. The most significant finding, however, is that none of the existing system appears to be capable of providing consistently superior performance across all criteria important to a firm from a strategic/competitive point of view.

4. Traditional PPC Systems Described

Given the above results and the predominance of ROP and MRP -based systems in use, we restrict our discussion to these two systems only. Readers interested in learning more about Kanban systems may refer to any of a number of textbooks such as Schonberger [19]. See also Karmarkar [13] for an exposition concerning situations where Kanban-based systems are not likely to be effective. Likewise, for learning more about OPT-based systems please refer to Goldratt and Cox [5]. It is important to recognize that almost all of the existing systems deploy a hierarchical decision architecture. The differences between the systems stem mostly from implementation details rather than conceptual underpinnings. They essentially adapt a 'divide and conquer' approach to decompose the problem based on either the product structure or the process structure. See Villa [26] for an exposition and analysis of alternative design approaches, via a unifying mathematical formulation of the production plan optimization problem, to recognize the main features of the existing PPC systems. The formulation also serves to compare the usefulness of alternative PPC systems in different manufacturing processes.

4.1. Reorder Point Systems

A reorder point system (ROP) is also known as a replenishment system. They are mainly concerned with determining answers to two basic questions: when to order (order timing) and how much to order (order quantity). Typically, such systems answer these two questions by first determining an 'economic' quantity for ordering and then determining a reorder point based on (1) estimates of lead time required to replenish the item and the variability in demand during the lead time and (2) a target customer service level specified by the management. Two basic types of re-order point systems are commonly found in practice: Fixed Quantity System or Fixed Interval System. In a fixed quantity system the order quantity is predetermined and order timing is allowed to vary depending on actual demand. In a fixed interval system, orders are placed once every P units of time, where P is predetermined, and order quantity is allowed to vary based on some predetermined target inventory level. It is important to recognize that several hybrid systems based on these two basic systems have been proposed in the literature.

It is clear that re-order point systems are simple in nature and are most suited for situations experiencing independent demand. One major flaw of such systems

concerns their lack of forward visibility. This severely curtails their effectiveness in situations where a part of the demand is "dependent" as in most manufacturing operations. Second, they assume a uniform and continuous demand. This is unrealistic in most manufacturing operations. Demand for components is often lumpy, time-phased, and not amenable to the traditional forecasting techniques. Third, placing replenishment orders solely based on inventory levels tend to generate work load that is highly erratic. Thus, often the factory is unable to handle them efficiently.

4.2. MRP-based Systems

Figure 1, taken from Kanet [8] illustrates what is meant here by the term MRP-based PPC systems. Central to the MRP-based approach is an MRP component inventory planning system, surrounded by other logistics modules such as master production scheduling, capacity planning, shop scheduling and control, and the like. Typically, the approach takes a set of forecasted customer orders and develops a master schedule of production. The master scheduling task is often aided by a "rough-cut" capacity planning module. The MRP "explosion logic" then orchestrates the release of production orders based on planned lead time and predetermined lot sizes. Planned order releases from the MRP inventory system are used to conduct "machine load" analysis for capacity planning. As orders are released to the production system, the factory scheduling module uses the MRP due date as a means for providing priority to orders as sequenced through the factory in competition for limited resources.

There are a number of fundamental flaws in the MRP-based approach to production planning and control. A central weakness is MRP's modus operandi of sequential, independent processing of information. The approach attempts to "divide and conquer" by first planning material at one level and then utilization of manpower and machines at another level. The result is production plans which are often found to be infeasible at a point too late in the process to afford the system the opportunity to recover. A second flaw concerns the use of planned lead times. Planned lead times are management parameters which are provided prior to the planning process and represent the amount of time budgeted for orders to flow through the factory. This can result in a tremendous amount of waste in terms of work-in-process inventory. Thirdly, MRP-based systems do not provide a well-designed formal feedback procedure instead depend on ad hoc, off-line, and manual procedures. When a problem occurs on the shop floor, or raw material is delayed, there is no well-defined methodology for the system to recover. Thus, the firm depends on and actively promotes safety buffers, leading to increased chances for missing strategic marketing opportunities. Fourth, MRP systems often produce schedules that are extremely nervous which, in turn, leads to reduced productivity and increased costs [23]. Firms resort to either freezing a portion of their master schedule for combating schedule nervousness or keeping safety stock of end products and, thus, incur the penalty of reduced customer service or increased costs [20, 21].

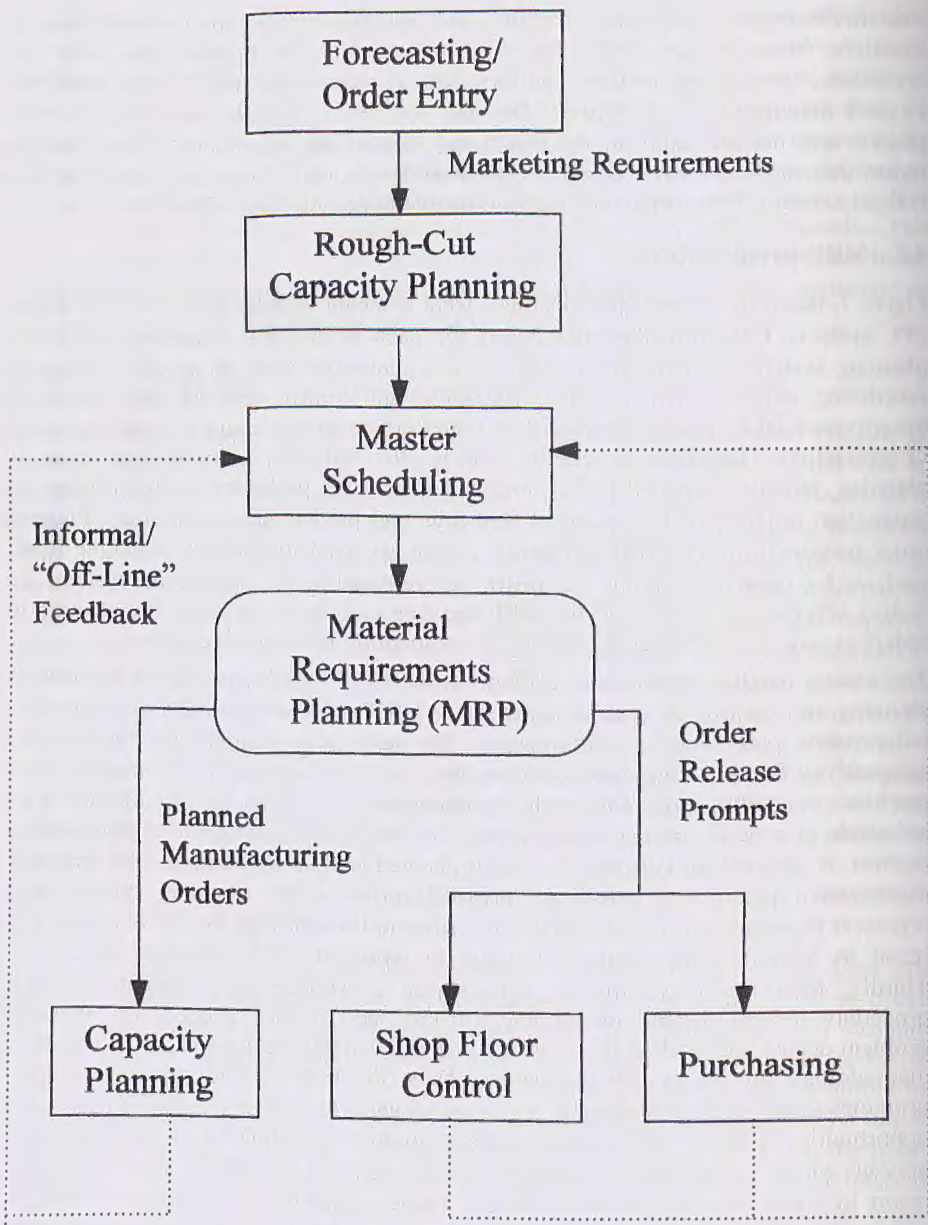

Fig. 1. MRP-Based Logistics System Architecture

Several empirical studies dealing with the practical issues surrounding efficient and effective implementation of PPC systems, in particular MRP-based systems, have appeared in the literature. See, for example, Monniot, J.P., D.J. Rhodes, D.R. Towhill, J.G. Waterlow, D.H.R. Price, and A.K. Kochhar [15]; Duchessi, Schaninger and Hobbs [4], and Kochhar and McGarrie [14]. Kochhar and McGarrie [14] report seven

case studies and face-to-face meetings with senior managers and identify key characteristics for the selection and implementation of PPC systems. They conclude that (1) the operating environment significantly impacts the choice of the system and (2) the existing framework for an objective assessment of the need for individual control system functions is largely inadequate in serving the needs of managers. This result demonstrates the need for a modular design and a decentralized architecture for PPC systems, thus providing individual companies the maximum flexibility in tailoring the system to meet their needs within a common framework. Such an architecture and design, in our view, should automatically preserve the best features of in all variants of the system and, thus, be able to guarantee efficiency and effectiveness.

5. Recent Advances

In spite of 20 years of advancement in computer capabilities, there has been little change in the basic design of production and inventory planning systems. Since 1970, the de facto standard for such systems has been material requirements planning (MRP). As discussed earlier a major problem with MRP is its use of fixed "planned lead times". Given a customer's date of need, planned lead times are used for planning the arrival of materials and the release of orders to a production facility. In MRP systems design, planned lead times are fixed parameters of a given inventory item and use no information regarding the sequence in which orders for items are eventually processed through the facility. Because sequencing knowledge is not used, planned lead times must be made large enough to accommodate the worst case situation. The end result is unnecessarily large inventories at every stage of the production process. In effect, under the current MRP regimen, the ultimate timing of how orders pass through the shop is treated as a random variable and an order's lead time is a conservative point estimate of its eventual flow time through the shop. This has led to a concerted effort to develop an alternative to MRP and it is heartening to note that some significant progress has been made in this arena.

In particular, a number of advances in applying computer technology have been made in the area of detailed scheduling and short term control of open manufacturing orders. Very notable is the rapid development of "leitstands" (computer graphics-based scheduling support systems) in Germany. Adelsberger and Kanet [1] characterize the emergence of electronic leitstand as one of the most exciting new developments in computer-integrated manufacturing. Leitstands make extensive use of recent advances in computer graphics to support human decision makers in manufacturing settings and fit perfectly into the CIM concept by connecting the planning module with the shop floor.

A leitstand is a computer-aided decision support system for interactive production planning and control [1]. The word "Leitstand" is German for command center or directing stand, and it is in Europe, and Germany in particular, that the leitstand technology is most highly developed. [9]. As Figure 2 shows a leitstand is comprised of the following five components:

1. a *graphics component* for providing visual representation of schedules (i.e., Gantt charts) for production resources;

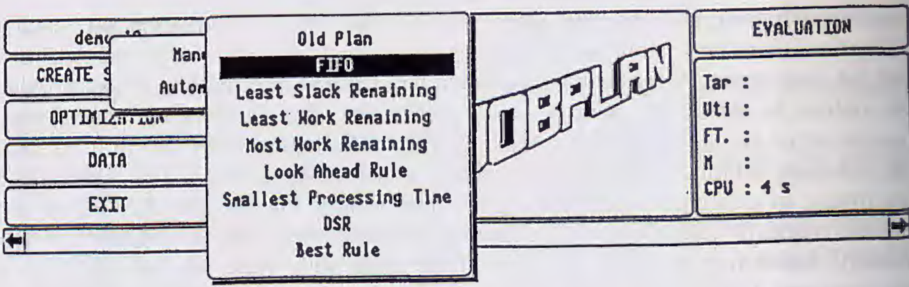

Fig. 3.a. Schedule Generation Strategies

Another attractive feature of leitstand systems is the ability to deploy advanced AI-based search methods. The types of approaches we refer to here include methods such as heuristic branch and bound, simulated annealing, beam search, tabu search, etc. Similar approaches that appear promising include application of genetic algorithms [10], application of basic decision theory [3, 12] and application of neural networks [7]. All these methods distinguish themselves from simple linear forward simulations in that they may include a (limited) capability for backtracking and/or the feature of dynamically changing the search path. Some of these approaches have the property that the more time they are given, the better the solution they produce. It is important to note here that such search methods can be made to run in the background so that the system is not tied up. This way, while the system is searching for a better solution the user can engage in other urgent/important work.

Current wisdom views the leitstand as a bridge between a firm's production and inventory planning system and its shop floor control system. A leitstand receives production orders from the PPC system (typically a manufacturing resource planning (MRP) system) and develops a feasible short term schedule for completing the orders as required. The leitstand uses information from the shop floor concerning the status of machines and open orders to determine the starting conditions for schedule generation. In attempting to develop a feasible schedule, a leitstand can uncover capacity problems and pinpoint exactly when and where future production bottlenecks will occur. In a limited sense, one can think of a leitstand as a tool for performing finite capacity planning, order scheduling, and production control -- all in one. We say these functions are limited because current thought on the role of leitstands limits the universe of orders which it must manage to those already released by, say, an MRP system. Leitstands can augment current MRP-based technology by providing a tightly-integrated method for short term capacity planning, production scheduling, and production control.

Perhaps the greatest virtue of the leitstand approach is that it facilitates rescheduling. In a typical manufacturing environment, any schedule, once determined, is almost immediately subject to new conditions, demands, and constraints. A leitstand starts with the schedule that was once valid (perhaps days, perhaps months ago) and helps a human planner process transactions (e.g., changes in machine availability, delivery of materials, changes in demand, etc.) to arrive at a new schedule.

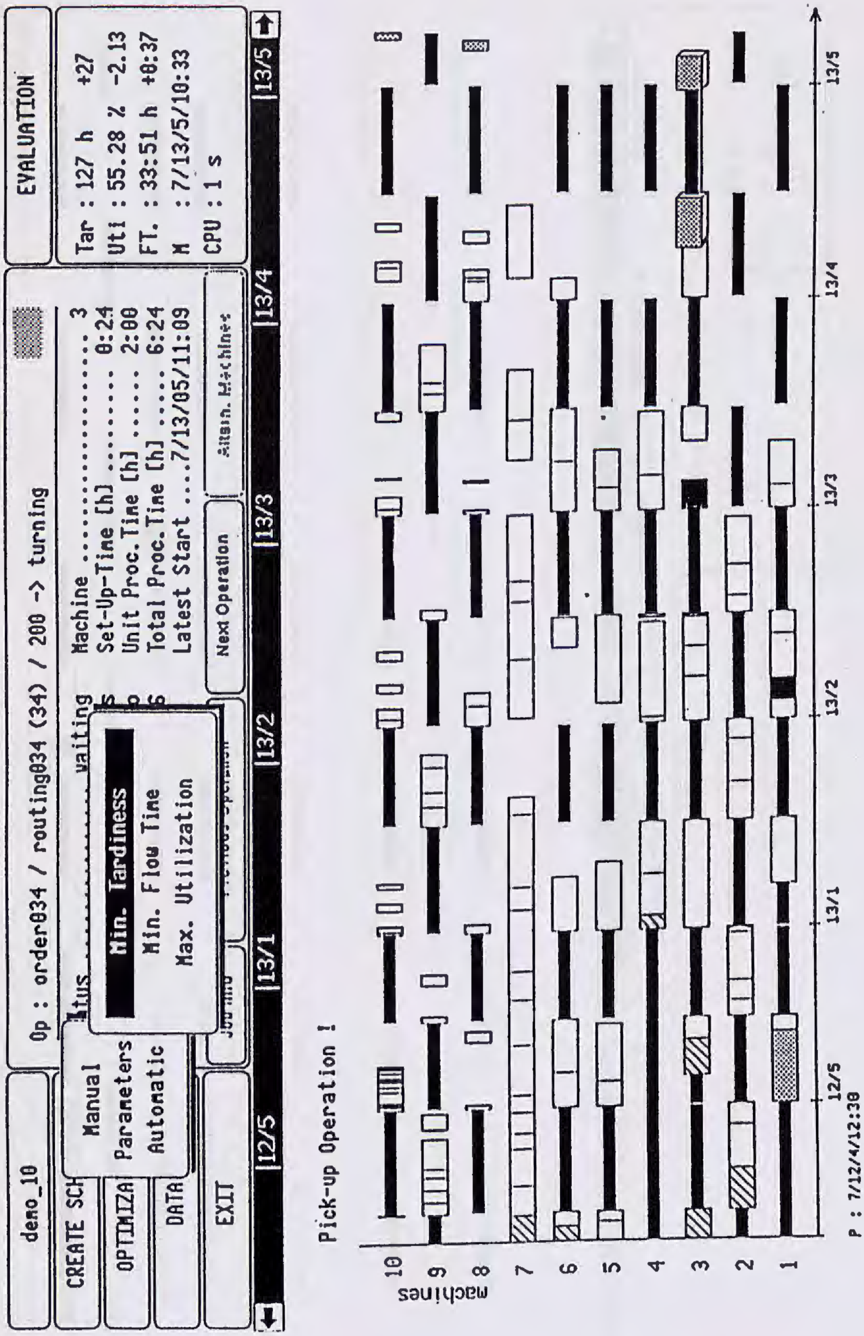

Fig. 3.b. Scheduling Objective

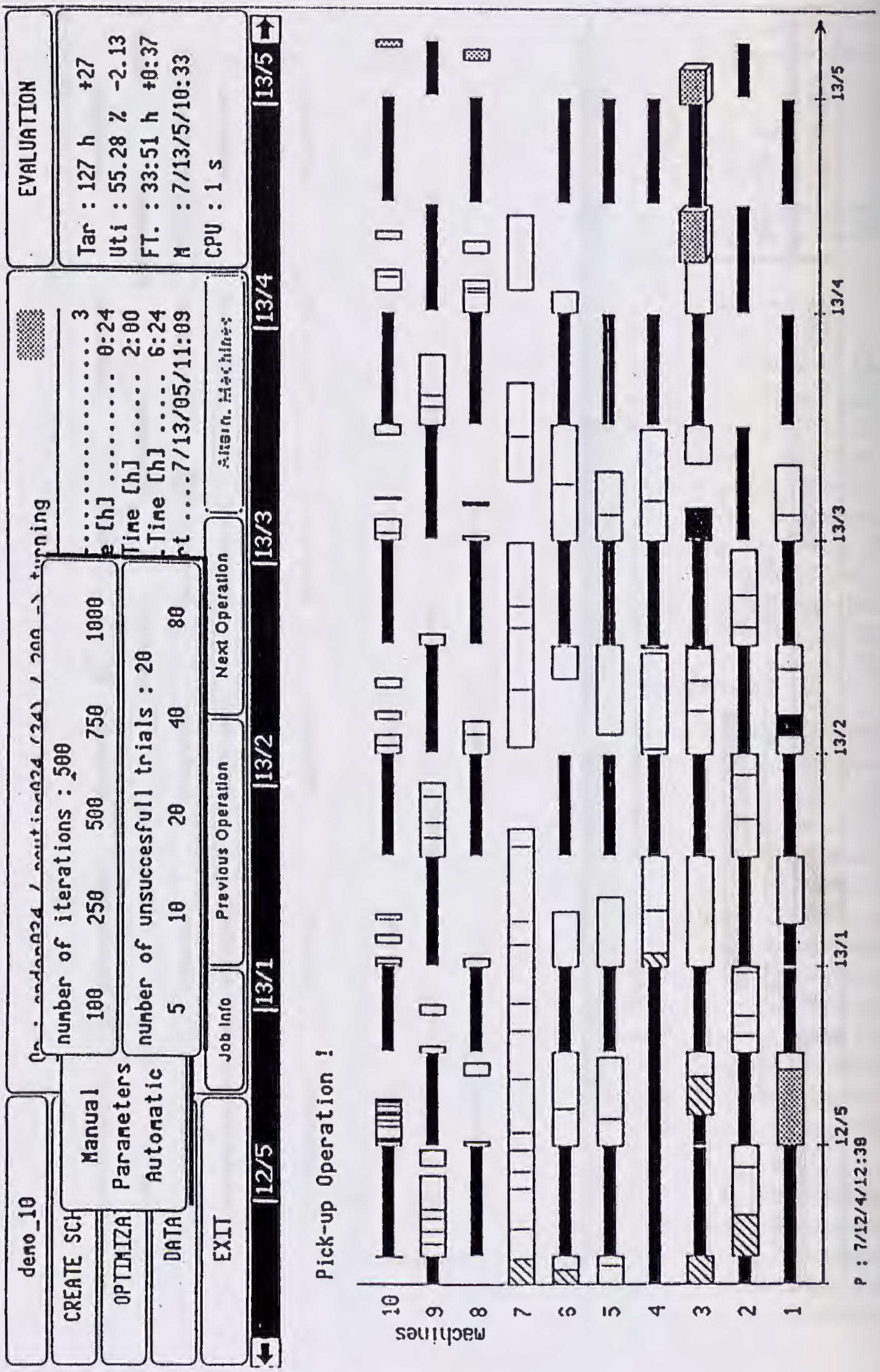

Fig. 3.c. Search Patters

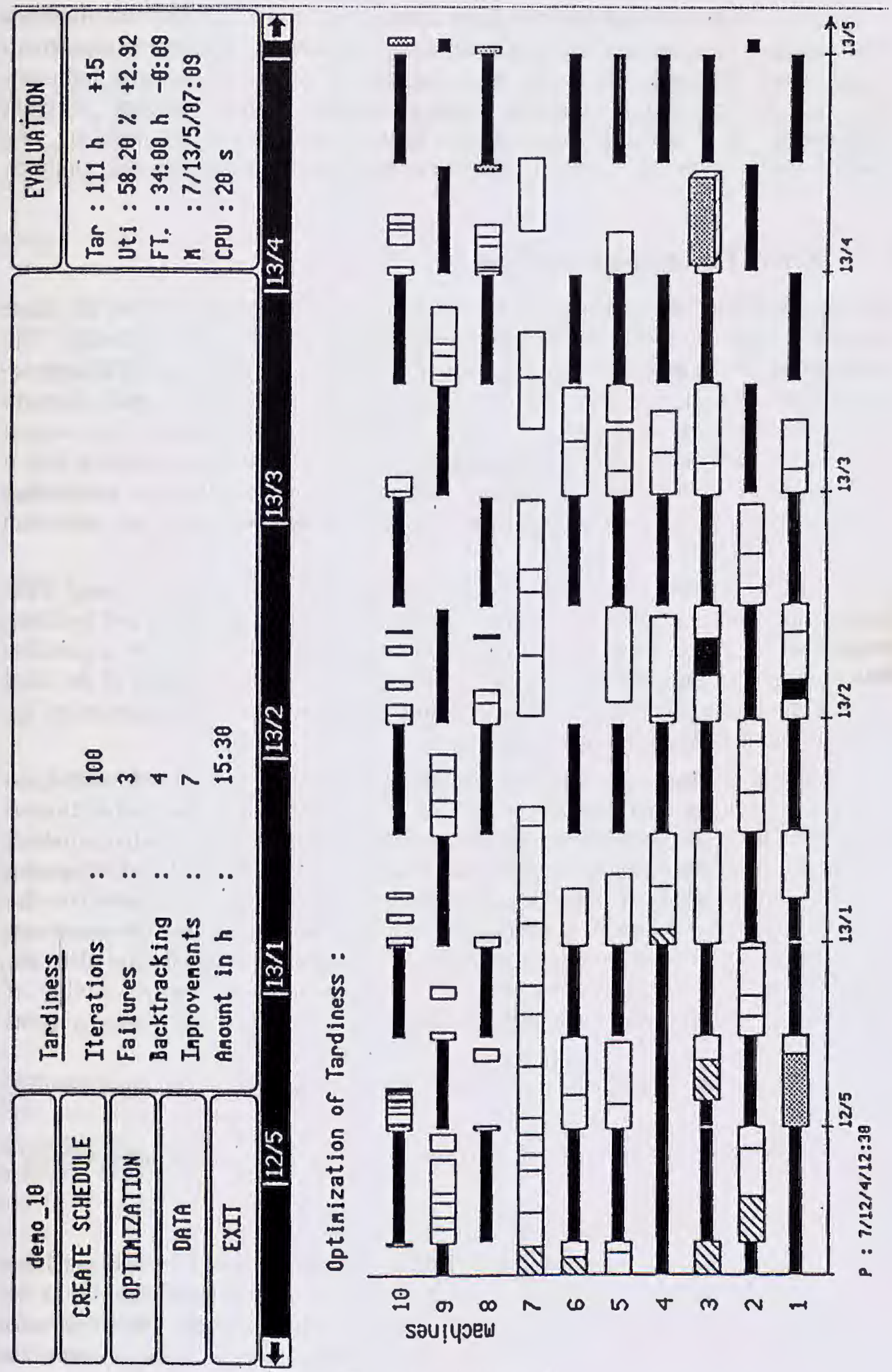

Fig. 4. Best Schedule Found

There is no doubt about the increasing demand for production planning methods which enhance a manufacturing unit's ability to reschedule. The entire movement toward "Quick Response," "Flexible Manufacturing Systems," etc., clearly indicates the need for production planning methods/systems which support efficient rescheduling. By offering a simple straight-forward approach to rescheduling, the leitstand model helps fill a critical void in current manufacturing planning methods [9].

6. A Newly Emerging Paradigm

The success of leitstands as a tool for short-term detailed scheduling suggests the same technology may be useful in the arena of material requirements planning. The advantage would be that in so doing the use of "planned lead times" would disappear. If a detailed schedule is maintained over a long enough horizon, then that schedule could be used as a planning tool -- for planning the delivery of materials. This would imply a completely new type of systems architecture for production planning and a major departure from current "stochastic" MRP-based methods. Because scheduling information would be used in detail we could justifiably call such an approach "deterministic" MRP.

Rolstads [18] calls for design and development of new computer based PPC systems since and provides an excellent overview of basic data structures and building blocks needed. The proposed model can be viewed as an architecture for a modular design for developing decentralized PPC systems. One of the advantages of the kind of design proposed is that it is extremely flexible and allows easy customization of the system to suit individual company needs.

Kanet and Sridharan [9] have also been promoting the concept of a decentralized production planning and control system in which computers and sophisticated algorithms play a key and central role. For example, they visualize a design in which individual workcenter managers (agents) each have a fully functional and integrated leitstand system which is capable of communicating with other agents in the production system. One major advantage of such systems may be that managers can electronically seek, obtain, and use information concerning the detailed shop plans for ensuring feasibility and 'optimality'. In order to determine the economic viability of such systems they recently examined the following questions using a single agent model:

a) how much better might such systems be in terms of inventory, customer service, and the like;

b) what is the impact of the operating environment on the extent of the improvement? and

c) are such systems feasible on a large real-world scale?

In a recent study, Kanet and Sridharan [11] analytically examine a single machine system; develop and test a heuristic for predicting the improvement that could be realized in more complicated multi-machine systems under certain conditions; and conduct a set of simulation experiments, of a general manufacturing system, to compare its operation under two fundamentally different policies:

Policy 1. Material deliveries planned using planned lead times as in MRP;

Policy 2. Material deliveries planned from a detailed schedule of operation.

For a single machine system operating under a policy of "forbidden early shipment," (where orders completed early are shipped only when they are due) and deploying the first-come-first-served priority rule and where every job has the same constant allowance A, the expected benefit ($\Delta\Im^*$), in terms of flow time reduction, of using is shown to be equal to $\Delta\Im^* = \dfrac{\rho}{-\log f_T + f_T}$ where ρ is the expected utilization and f_T is the fraction of orders expected to be tardy. From Little's Law it is clear that this reduction in flow time leads to a proportional savings in inventory related costs. Thus, the expected savings in raw material inventory, for various values of ρ and f_T, is as shown in Table 3.

Utilization	Fraction Tardy f_T		
ρ	.05	.10	.15
.75	25	31	37
.80	26	33	39
.85	28	35	42
.90	30	37	44

(The numbers shown in the table are in percentage)

Table 3. Expected Benefit of Using Scheduling Information: Single Machine Case

Extending their analysis to a multi-machine system where individual jobs are independent (i.e., no dependency between items as in an assembly) and when each job has a known probability p_i that it will require i operations they derive the heuristic expression to estimate the approximate expected benefit, in terms of reduced flow time:

$Expected\ Benefit = \sum_i \frac{p_i}{i} \Delta\Im^*$, where $\Delta\Im^*$ is the expected benefit for the corresponding single machine problem. The above expression assumes that (1) the jobs are independent (no assembly is involved) and (2) the order allowance is constant. Its validity was tested via a set of simulation experiments using an eight machine job shop. In the simulation experiments the average number of operations per job (n) was varied at four levels and the target shop utilization was varied at three levels. The four levels considered for the number of operations were: (1) every job has exactly one operation (n=1), (2) a job has one to five operations with equal probability (n=3), (3) a job has one to nine operations with equal probability (n=5), and (4) every job has exactly eight operations (n=8). The three levels of target shop utilization examined were 75%, 85%, and 95%.

number of operations per job. Both order allowance method and sequencing rule have a significant impact on IMPRVMNT. However, their influence decreased as the average number of operations per job is increased. The results also showed that under all conditions examined the policy of using scheduling information for coordinating material delivery dates produces consistently lower average flow time values. For each combination of factors tested the actual benefit was significantly greater than zero. For the case where the number of operations per job ranged from 1 to 9 (average number of operations per job = 5), utilization ratio was 0.85, the job sequencing was done using OPNDD, and job allowances were set using the NOPS method, the 95% confidence interval for the expected benefit was found to be in the range 7.89% to 9.08%, indicating that systems which use the scheduling information for planning material requirements are likely to produce a significant amount of savings in inventory related costs.

These results are important not only because they show to what extent MRP-based systems can be improved, but also because they demonstrate how such improvement could be readily accomplished. What this preliminary study has in fact shown here is a simple "patch" to the inherent problems in MRP systems that arise from the use of fixed planned lead times. To expand on this idea, consider altering MRP systems in the following way: Change all planned lead times to some number greater than the length of the planning horizon. This will ensure that no shop order is ever un-released to the shop scheduling system. Let the shop scheduling system then establish a shop schedule and use this schedule to derive a schedule of planned order releases for all raw materials. The difference in this approach and the MRP-based approach is that MRP uses planned lead times to estimate the offset needed for manufacturing operations instead of deriving a schedule to see what offset is really needed for each manufacturing order.

Not only is the above patch straight forward, but the computational experience leads to the conclusion that such a procedure would be quite possible in even large scale practical settings. For example, Kanet and Sridharan [11] were able to completely rebuild entire schedules for their model factory in less than 5 minutes using relatively modest computational facilities (an 80386 PC running under DOS 6.0 and Windows 3.1 operating systems.) For example, at the extreme, this required the rescheduling of 5000 manufacturing orders with eight operations per order so that approximately 40,000 operations were scheduled. Moreover, the procedure we describe is polynomial in the number of operations to be scheduled.

7. Conclusion

Current thought on the role of so-called “finite” scheduling systems limits the universe of orders which it must manage to those already released by an MRP system. The next step would be to expand the scope of these systems so that they can supplant current MRP-based technology by providing a tightly integrated method combining order raw material planning with production scheduling and control. The above results represent a first verification that such integrated planning systems are beneficial and feasible on a practical scale. From here a number of questions remain open. First, in many real life factories the jobs are dependent (e.g., components and assemblies). So it would be important to study the behavior of the above approach in more

complicated environments such as when jobs are dependent. A second question is what would be the impact of a rolling horizon with changing demands and new shop conditions. The concern here is whether or not such systems would introduce excessive "nervousness" in the raw material plans and thus prove to be counterproductive. Finally, testing the above approach in other types of shops (perhaps with different routing patterns and processing time distributions) are the next important questions to be addressed in this line of research.

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