Abstract

True closed loop performance in an MRP system would imply that the component level releases produced by the system are realistic. In dynamic shops, this requires a finite capacity scheduling system. Such systems are becoming available; however, at present, there appears to be no commonly understood way of integrating them with MRP. In this paper we discuss the different approaches that are emerging. In particular, we discuss the approach taken with the scheduling system CLASS, which was specifically designed to co-ordinate with MRP systems. Integration of this system with existing MRP systems is described with examples.
Introduction

The term "closed loop" as used in the MRP literature and in practice, appears to have two somewhat different meanings. In one case, the sense is of closing the control loop between master schedules (end items) and order releases (components) so that they are consistent. In other words, a feasible master schedule is created, that results in a feasible component level order release plan, through which the master schedule can actually be carried out. One realization of this type of closed loop in MRP, is the use of "Rough Cut Capacity Planning" to evaluate the feasibility of an order release plan, and to feed back the results to the master scheduling level to change the master schedule.

The second use of the term in the MRP context is in the sense of feedback of actual performance on the floor to the MRP system through shop floor data collection. In this sense, the progress of work orders and resulting changes in scheduled receipts of completed orders are fed back to the MRP system. Over time, the MRP system and reality are brought into synchronization through this process and order release plans are revised accordingly. This is a rolling horizon approach that is in fact more akin to open loop or "feed-forward" control.

Both these aspects of MRP are important for effective production control. However, we use the term "closed loop" to refer to the development of consistent master schedules and component schedules through a control loop that includes decision making. We use terms like "shop monitoring", "status reporting" and "shop data collection" to refer to information feedback from the factory, that updates the MRP data base.

In the following, we focus on closed loop control effected by use of detailed scheduling. We first discuss the shortcomings of MRP in this respect, and the
limitations with techniques like "rough cut" capacity planning. Alternative approaches towards integrating scheduling with MRP are described and compared. An approach which clearly separates the scheduling and material planning functions is described as "firm" integration of the two levels. Finally, the role of shop floor monitoring in this integration is described with CLAS/SL as an example.

Capacity Loading and Lead Times

MRP has often been described as an approach that "loads to infinite capacity". However, while there is no direct consideration of capacity limitations in MRP it should be recognized that lead times are an indirect way of capturing this information. As capacity loading and utilization increases, work has to be deferred to later times due to queues at resources. The result is longer lead times. Thus MRP does have a mechanism, however limited, to capture some loading effects. The real problem with using lead times is that MRP can only employ a single lead time for a given part or item. In fact, a fundamental flaw in the MRP "model" is to take this lead time as a property of a part (as captured in a part master file) rather than a property of the plant and its level of loading.

As a result, MRP uses lead times in making releases, but it is these very releases that impose a load on the facility, and determine its lead time behavior. Unfortunately, there is no mechanism within MRP to make the assumed lead times consistent with the created lead times. One way to think about true closed loop control is in terms of consistency of the order plan: the lead times implicitly or explicitly assumed in making order releases should match the lead times that are actually created by the releases themselves.
There have been some attempts to enhance MRP to correct this problem with capacity loading and lead time. These include methods such as "Rough Cut Capacity Planning", and "Capacity Requirements Planning". Unfortunately, they have for the most part focussed on capacity limitations rather than their lead time consequences. Figure 1 shows how such a method (there entitled "capacity analysis") might be used to analyze an order release plan, and to determine whether capacity limits are violated. If not, the order plan is feasible; if they are, then some action is required, in terms of capacity addition or adjustment of the Master Schedule.

There are some things wrong with this picture. First, Rough cut and other standard capacity analysis methods, themselves have to be given the time taken for an order to reach a given work center. They do not actually compute the queue and move times as a consequence of loading. Thus they suffer from the same problem that MRP does. Second, the feedback loop of Figure 1 is not part of the system, but is outside it. There is little help from the system in determining what is the best or even a feasible way of solving the problem. Third, even if the right answer is known, it often cannot be implemented via the MRP system. For example, the right action to take might be to shift a due date on a particular end item order on the master schedule, and to increase its lead time, because of heavily loaded capacity. As an analogy, if a manager's calendar is very full, and a project cannot be done on time, it may be necessary to both defer the completion date for the project, and to start it earlier than normal. This MRP cannot do; the best that can be done, is for the order planner to intervene, and adjust the order lead time at the point of firming the order.

In sum, at the current level of development of capacity analysis procedures, and with the lead time limitations within MRP, closed loop control is simply not possible. Furthermore, in order to ensure consistency of order release timing
Figure 1: Capacity analysis for evaluation of order release plans in an MRP system.
with lead times, it appears that an approach has to be used that both respects capacity limitations, and converts the constraints into their lead time consequences. In more stable environments, this can be done by open loop methods. For example, Karmarkar (1987), Karmarkar, Kekre and Kekre (1985) and Karmarkar, Kekre, Kekre and Freeman (1985) describe such a method for a repetitive manufacturing facility. Bacon and Choudhuri (1987) compare the performance of such methods with detailed scheduling. However, in dynamic facilities with variable lead times, it appears that detailed scheduling is the viable approach (e.g. Karmarkar and Shivdasani, 1986).

Scheduling and Simulation

There are several distinct approaches that are available for evaluating the consequences of an order release plan, and for determining a detailed operations schedule. They broadly fall into two classes: simulation and scheduling. The distinction is that the latter involves the generation of a schedule which is in some sense a good schedule, whereas simulation is a passive evaluation of the result of order releases. The distinction between the two classes is somewhat blurred in the sense that a simulation with built-in dispatching rules falls on the boundary. Within the category of scheduling methods too, there is a large degree of variation in the extent to which optimization is pursued, and in the underlying technology or methodology. In this paper, the intent is not to compare the relative scheduling performance of alternative approaches or the merits of different methodologies. Rather it is to discuss alternative ways of integrating the detailed schedules that are produced with material planning. It should be noted that the methods that are available vary in how they can interact with a material planning system.
For example, there are a number of simulation packages available, that can be used to build a simulation of the factory. This simulation can then be used to evaluate the consequences of an order plan. In addition to general purpose simulation languages such as SIMSCRIPT, GPSS, and SLAM, there are simulation languages designed expressly for manufacturing systems. These include SIMAN, XCELL, and COSMOS. In addition, the FACTOR simulation package has been developed for the specific purpose of evaluating the consequences of MRP order release plans. Many such simulations have been built, many of which incorporate dispatching rules. One of the best known early efforts was the job shop simulator due to Markowitz.

Among scheduling systems the two broad classes of schedulers appear to be those based on expert or knowledge-based systems, and those based on optimization or model based heuristics. In fact the difference between these two approaches is not that great. It is very difficult to distinguish a set of model based heuristics from a set of expert decision rules on any fundamental grounds. It could perhaps be argued that the knowledge based systems are oriented towards more uncertain environments where significant modification of rules is likely to occur over time. The model based methods are directed towards more stable structured situations. In the opinion of the authors, these directions will tend to converge over time to a composite form. A variety of expert systems have been reported on recently; perhaps the best known effort is ISIS (Fox and Smith, 1984). Among the model based systems are CLASS (Dobson et al., 1988) and SCHED-STAR (Morton et al., 1988). It is conjectured that OPT (for example Jacob, 1983; Fox, 1982) is also such a system, although this is a guess since the methodology behind OPT is not generally known.

Also within the class of model based systems are certain systems that combine material planning and scheduling. The MIMI system (Collins, 1988)
treats material as an input resource at the operation level. Thus it makes
decisions on material allocation and presumably generates purchasing orders.
The "Production Reservation System (PRS)" (Conway and Maxwell, 1988),
interweaves order generation, material allocation and scheduling. Orders are
generated when material is unavailable, and the order is then immediately
scheduled at the appropriate facility. The COMETS system (Golovin, 1988)
includes material planning, facility loading and detailed scheduling. However,
the specific nature of the interaction between these levels is not known (to the
authors).

In the next sections, we describe and discuss some of the alternative
strategies that appear to be available for combining detailed scheduling (or
simulation) with material planning decisions.

Weak Integration: Order Plan Evaluation and Stand-Alone Scheduling

The simplest integration approach is perhaps to use the simulation or
scheduling system as an evaluation tool, much as capacity or loading analysis is
used. Figure 2 shows this approach. The difference, in relation to capacity
analysis, is that the scheduling and simulation approaches directly produce lead
time information. However, simulation and scheduling methods can give vastly
different results.

A simulation, or a forward scheduling technique is only able to take orders
and release dates as generated by MRP and to evaluate the consequences with
respect to completion dates. This information can be used to change scheduled
receipt dates for orders within MRP, at the point that they are firmed. However,
it is not possible to ensure that due dates on particular orders will be met, except
by changing priorities on these orders and re-running the simulation. Thus if
orders are being completed too late or too early, the changes in MRP have to be
Figure 2: Weak integration of scheduling and material planning
made manually, and changes to the simulation rules have to be made by trial and error.

A backward scheduling method can achieve the opposite effect. Given due dates, it can in principle determine order release dates such that the due dates would be met. The primary value of backward scheduling is the somewhat negative one of indicating when there is a problem with the release plan. This is indicated by negative release dates from the backward schedule. However, there may be no indication or indeed any simple way of correcting this problem. If this does not occur, the backward schedule can determine the latest possible dates at which orders can be released and still make the desired completion dates. In principle, using these release dates will lead to a "JIT" schedule with the smallest level of WIP in the facility. However, this WIP and leadtime reduction can be somewhat deceptive. If purchasing is driven by MRP releases, then typically, raw material and purchased parts are already committed. Delaying release dates will not make any difference to the cash flows associated with these purchases.

A true scheduling system should not only determine the latest release dates for those orders which can be feasibly completed on time, but should also determine a best effort schedule for those items which will be unavoidably late. This best effort should be able to trade priorities across orders as well as recognizing that excessive effort at expediting certain orders may lead to delays on others. Thus the output of a true scheduler, used in an evaluative mode, can not only indicate the tightest release plan, but also those orders that ought to be delayed, and where the customer must be informed. If the "customer" is an order within the factory for a parent item, its release date should in turn reflect the delay. This will only occur on the next occasion that material planning is performed, and the delayed availability of the child order becomes known to
MRP. The problem here is that MRP may well generate a new planned order at the earlier date, preceding the delayed (firm) order. This raises the issue of keeping the pegging or material allocation assumptions of the scheduling level consistent with those in the material plan.

The scheme described above is the least invasive and least tightly coupled approach to enhancing material planning with a more detailed view of the shop floor. Consequently, it is relatively simple to implement. For the most part, information is passed from material planning to the scheduler (or simulation) and material planning is left more or less unchanged. The feedback from the scheduler to material planning is left to human intervention.

Firm Integration: Pegging and Firming

In this approach for integration, material usage at the detailed level, as assumed by the scheduling system, must be consistent with the material allocation made by MRP. The scheduling system cannot therefore, second guess MRP with respect to material allocation either in terms of the allocation of existing inventories, or in terms of the use of material from purchase orders or factory orders that are yet to be completed. This consistency in essential to allow the MRP system to continue being the data management hub for generating work orders and for recording information on order status and shop status.

An implication of this consistency requirement is that if an order is delayed by the scheduling system, all other (parent) orders to which that order is allocated, must be delayed accordingly (as was discussed in the last section). In other words, in this higher level of integration, the material allocation and pegging relationships created by MRP are respected at the scheduling level.
This requires that the scheduling system be explicitly able to capture and use pegging and allocation information.

To implement this approach, in addition to planned orders, pegging relationships between orders are passed to the scheduling system from MRP. In scheduling orders, the scheduler respects these pegging relationships. One advantage of this scheme is that the scheduler can reschedule start and due dates for all orders down to the operation level, and still maintain consistency with the MRP system in terms of material allocation and use. Karmarkar (1989) uses an analytical model and demonstrates a decomposition based on pegging relationships that results in consistency. The changed start and due dates can also be fed back to the MRP system as a process of firming the planned orders. If this is done, the scheduling level and material planning level can be kept in synchronization, at least up to the scheduling horizon. Furthermore, the scheduler is able to reschedule the orders so as to change their release dates, and the work orders can still be generated through the MRP system so that there is no change in procedure as far as the shop floor is concerned. This integration scheme is shown in Figure 3.

It should be recognized that the maintenance of pegging relationships as set by material planning, does reduce the freedom available to the scheduler. It may be that if the scheduler were "allowed" to redo material allocation, it would find a better allocation and a better schedule in terms of some scheduling objectives. Figure 4 shows this limitation schematically in terms of inventory for part A which goes to an order of component C and a factory order for part A which goes into an order for subassembly D. While the timings of these orders can be changed by the scheduling level, the pegging linkages between them have to be maintained, so that D cannot be started till the order for A is
Figure 3: "Firm" integration of scheduling and MRP
Figure 4: Allocation of available inventory of A to C, and pegging of an order of A to an order for D.
complete. It could be that material could be reallocated to start D instead of C, but the scheduler would not be allowed to do this.

The advantage of this scheme is that there is a clear separation of function between material planning and scheduling. Material allocation is actually a valuable prioritization device for the planner using an MRP system. For the scheduling level to second-guess these decisions is risky, since they involve organizational considerations and perhaps customer priorities that may be difficult for the scheduler to understand and manipulate. The limitation on scheduling is a small price to pay for retaining the material allocation function at the material planning level in a form familiar to planners.

The other pragmatic advantage of this approach is that the choice of an MRP system can be made relatively independently from the scheduling system. Many MRP systems serve as communication and coordination points and data base management hubs for the firm (Karmarkar and Shivdasani, 1988). There are MRP systems that have been specialized for particular kinds of businesses such as defense contracting, chip fabrication, pharmaceuticals, fine chemicals, repetitive rate based production and so on. The independence of choice provides a greater set of options.

With some MRP systems, there may be difficulty in obtaining the appropriate information out of the system. This is not a difficulty as long as the data base management scheme used by the MRP system, can be accessed. Consider the example of MAPICS, which is IBM's S36/38 and AS400 based MRP system. The difficulty in extracting the right information from MAPICS to go into a scheduler, is that pegging information is not available. Although a pegging report is produced that pegs all open orders to end items, the report is not informative, since the end item order number is simply carried through to the component item number order. Furthermore, planned orders are not included in
the pegging report, whether they are parents of open orders or not. In effect, the required pegging information is indeed generated, but is contained in a work file which is discarded.

With any MRP system that does not provide this information, the appropriate material allocation rules have to be reproduced to create the pegging file. These pegging rules generally take a form such as the following:
- First allocate available material to end item customer orders in due date precedence.
- Next allocate material to firm orders, in order of earliest requirement date.
- Next allocate material to planned orders in order of earliest requirement date.

Given the open order, firm and planned order files, and the appropriate BOM relationships, it is possible to work through these files, and reconstruct the pegging report. This can be done with MAPICS, although extracting the right information requires detailed knowledge of the data storage scheme and file structure. When a standard data base management scheme is used, the data extraction problem is clearly simplified. For example, certain MRP systems such as MM3000 and MANMAN on the HP3000 use the Image data base management system.

**Tight Integration: Combined Planning and Scheduling**

There are several production control systems that combine both material planning and scheduling in one application package. Such systems include OPT, the PRS system, and MIMI. For details regarding OPT see Jacobs (1983) and Fox (1982). The authors do not have detailed information about this system. However, it appears that it was originally intended to work directly with demands and to produce a detailed schedule that would meet this demand. Recently, there have apparently been modifications made to allow the system to
interface with MRP systems, at least in terms of data input. It is not clear whether consistency with MRP material allocation is maintained. The MIMI system apparently imbeds material planning as well as scheduling within it, so that there is no separate material planning level. From Collins (1987) it appears that MIMI schedules each operation and plans material usage at the operation level rather than the route sheet level. This is actually a natural way of handling material management in a chemical batch process environment.

The PRS system is very explicit in combining material planning and scheduling. The concept behind the system, as its name suggests, is analogous to say an airline reservation system. When an order for an end item is received, it is entered and checked against available inventory of the item. If there is insufficient inventory a build order for that item is generated, and scheduled at the "best" time on the appropriate resource. Given the time of scheduling, material availability for the inputs required is checked. If material is available, it is reserved and the process stops. If some item (child) is not available in sufficient quantity, an order is generated for that item, with a due date corresponding to the build date of the parent. The order for the child item is then also scheduled, in turn checking on material availability, and so on recursively. If the child item's order cannot be scheduled in time for the parent, the parent items order is also delayed and shifted accordingly. The system then immediately resolves both material allocation and detailed scheduling of all needed subassembly and part orders. When new orders are entered, they are scheduled in at the best available times.

Apart from the interleaving of planning and scheduling, the interesting thing about this system is that it is a form of pull process, where items are scheduled as orders appear. There is a tendency to give early arrivers precedence in both material allocation and resource time. Note that this is not necessarily the
material allocation rule that is used in MRP systems where typically, all else being equal, the order with earliest due date would capture material first. The PRS system seems especially well suited (as Conway and Maxwell point out) to situations where final assembly and subassembly are done with short turnaround times, to respond quickly to demand. For example custom assembly and subassembly from available parts, would be a good application.

While all of these tightly integrated systems have their applications, they have the following shortcomings. First, combining material planning and scheduling means that the same decision horizon is being used for both functions. This may be highly inappropriate where the planning horizon is long. For example, if there are purchased materials or fabricated parts which have a long horizon, the scheduling system is forced to look out to the longest lead times. Developing a detailed schedule at the job step level, for such lengthy periods is not a useful exercise, since there is little chance that such a schedule bears a close resemblance to future events.

Secondly, this integration also makes organizational integration of planning and scheduling necessary. This may be very undesirable. Usually, planning decisions have to do with coordination inside and outside the firm, involving interactions with other functions and with vendors and customers. Scheduling on the other hand, is an activity largely internal to manufacturing and high localized in terms of the expertise required. Except in small shops, these functions are organizationally separate.

Thirdly, the material allocation decision is now imbedded inside the scheduler, and furthermore, there is no firming process available to the material planner. This removes a degree of control from the floor and gives it to the system. Since these decisions may involve political issues and questions of customer importance, equity and so on, it seems risky to assign them to a code.
Fourthly, as we have mentioned, the separate choice of an MRP system and a scheduling technique is precluded, and the former comes with the latter. Finally, the modern MRP system has many data processing functions including interfaces to inventory status reporting, purchase order generation and communication, receipt and shipping of goods, lot tracking, quality management systems, labor reporting, costing and so on. If a scheduling system is to take over material planning functions, it also needs to incorporate these data management activities and interfaces. This places a severe and unnecessary burden on scheduling systems, particularly since these functions are already available off the shelf. It also means that if any customization of data processing interfaces is required, it has to be done by going into the innards of the scheduling system. In our experience, this is something to be avoided strenuously. Scheduling is a hard enough task as it is.

Integration with Shop Floor Data

A second aspect of loop-closing in material control, as discussed in the introduction, is to return information on actual events and shop status back to the material planning level. If we consider what this set of information is, it is clear that only a part of the information can be understood or absorbed by the material planning level. In particular, MRP systems can only absorb information on changes in the scheduled receipt date, and on quantities completed. It is true that many MRP systems can store and record other kinds of detailed information such as current status of open orders. However, the system does nothing with this information, it is simply held passively and it is up to people outside the system to figure out the consequences. In other words, current shop status and order progress does not translate easily into a prediction of when the
order will be completed, and in what quantity. MRP systems do not help in this prediction task.

Even worse, the MRP system can use information on completion times and quantities to some extent, but it will not necessarily come close to taking the right corrective steps. Thus inventory records will be more accurate, but the MRP system will not necessarily be able to automatically identify which parent and end item (planned) orders should be rescheduled or replanned. Instead, a typical MRP system, when faced with a late completion of an open order, will simply generate new orders to meet the schedule for parent items rather than correctly delaying those orders, and reflecting the delay all the way to customer orders. In other words, it will take the right action in terms of quantities since it will make up any shortfall in production, but it will not be able to take the right action in terms of timing. As we have pointed out earlier, this is the weakest aspect of current material planning systems. Even in terms of quantities, the shortfall (due to say yield problems) may be identified too late -- at the time the order is completed.

The point being made here, is that even with the second data-collection aspect of loop-closing, MRP systems are unable to completely close the loop even after the fact. The logic of MRP prevents the right corrections or adjustments from being made. Here again, it appears that a scheduling system or some other enhancement is necessary, to enable MRP systems to catch up to the facts as soon as they become known.

To illustrate the role of a scheduling system in absorbing current data, consider a shop floor data collection system in which open order status is reported say once a shift. Suppose that the information set that is collected consists of the location of open orders, in terms of the quantities at each operation (job step). Note that this implies that orders may have been split into
transfer batches which may be scattered over several points on the job's route. Furthermore, if there have been yield problems, the quantities may differ in total from released quantities. Finally, if some of the parts have to be reworked, they may already have been collected into a rework lot and routed to the appropriate location. The first question that arises is: where will this data be stored after it is collected? Some MRP systems (MAPICS for example) are able to store such information. Others are not, in which case some enhanced data management capabilities have to be provided. Hereafter assume that such a capability is available, either in the MRP shop floor module or in an enhancement. The scheduling system has to be able to access this data. Once this is done, the scheduler can be run to generate a new schedule, given current shop status as a starting point. The scheduling system must therefore have the capability to correctly represent the current shop status as initial conditions for the scheduling problem in terms of the distribution of transfer batches for each open order, as well as machine status (including current set up condition, up or down status, and time to availability if down). Given that these abilities are present, the scheduling system can generate a new schedule which then predicts when the open orders will be completed, and also predicts the impact on the parent orders to which these are pegged. Many MRP systems cannot accommodate shop data to the extent of detail that is needed. Others can store the data, but are not able to function in real time, or do not have links to real time shop floor data acquisition systems such as bar code readers. There appears to be a class of shop floor data management systems emerging that is aimed at enhancing MRP systems to provide this capability. Other such systems are designed to replace MRP systems and provide complete factory management capability in one package. The issue here is similar to the one discussed above in terms of the different degrees of
integration. The enhancement approach can provide more flexibility in the choice of the pieces of the system, and need not render existing applications obsolete or unusable. On the other hand, it has been argued that the tightly integrated single package solutions, make fewer compromises and make a turnkey approach possible, which might reduce startup time. Examples of some of the "open" systems that are appearing are Striped Lightning (Peripheral Software Concepts), Workstream (Consilium) and Delta (American Cimflex Teknowledge).

As an example of a "firm" approach to real time loop-closing using shop floor data, consider the approach being applied with the CLAS/SL scheduler. Here the scheduling system runs on a work-station and may schedule part or all of a manufacturing facility. At any time, the scheduler has produced a detailed schedule based on MRP order releases, and pegging information. With current shop floor data available in real time, the scheduling data base can be updated, and the schedule regenerated at any time. In practice, the schedule would be regenerated when there was some specific reason to invalidate the last schedule (such as a machine failure or substantial yield problems). The schedule may also be regenerated if the cumulation of small errors and variations causes current status to be sufficiently different from that previously predicted by the schedule. This kind of "drift" will occur in any real system, just from random variations in set up, processing and move times.

Figures 5, 6 and 7 show the approach in the CLAS/SL system which represents the combination of the CLASS scheduler with "Striped Lightning". Striped Lightning(SL) is a data acquisition and data management system that is able to track and maintain every transaction that occurs at the material planning level, as well as shop floor transactions that are not accomodated by MRP. In fact SL is intended to automate the substantial data acquisition and entry
problem that is faced by any MRP system. The scheduler on its work station, is on a local area network (LAN) and the SL system puts out on this LAN any transactions either in the MRP system (following a regeneration run), or on the floor, that could be of interest to the scheduler. These are picked up on the work station, and used to keep the scheduler's data base current at all times. A scheduling run can be initiated either automatically via a message on the LAN or locally, depending on what is appropriate. The schedule that is produced is then based on current information. In the CLAS/SL system, this information would include order status, transfer batch location, material availability (physical), tool availability, labor and machine status.

Conclusions

The term "closed loop" as used in material planning really has two meanings: one is the closing of the material control loop in the sense of producing consistent order release plans and master schedules; the other is to close the loop from actual events on the shop floor to the assumptions made at the planning level. With respect to the first sense of the term, it has been asserted that detailed scheduling is a necessary ingredient to achieve true closed loop performance. Three approaches to using scheduling systems, with varying degrees of integration with material planning, were described. It seems clear that without the use of a detailed picture of capacity usage at the operation level, consistent master schedules and order releases cannot be developed in the general case.

It has also been argued here that closing the loop in the sense of shop data collection is also likely to be ineffectual in the absence of a scheduling system. This is because conventional material planning methods cannot use or absorb all the data on shop status that can be collected. This statement may be more
surprising, but some reflection will reveal its validity; in fact this is one of the reasons that the addition of shop floor modules to MRP systems (without scheduling capability) has not had an especially salubrious effect on the performance of MRP.

It should be noted that these statements are directed towards the case where production lead times are variable. In situations where lead times are very stable, there is in fact less need for closed-loop performance, and open loop methods can work quite well (for example, see Bacon and Choudhuri, 1988).

The interesting development that is occurring today is the appearance of shop floor data acquisition and management systems that significantly increase the ability of MRP systems to have shop floor status available on a real time basis. These systems, in conjunction with newly developed scheduling techniques, present the possibility of manufacturing control with true closed loop performance.
Figure 5: Integration of MRP, scheduling and shop data collection using the "Striped Lightning" and CLASS systems.
Host Computer System

MRP-II → Striped Lightning

Log File → Is transaction of interest to the shop floor? If yes, send out on LAN → LAN

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**Figure 6:** Real time transaction monitoring and message generation by Striped Lightning.
Is info. on LAN interesting to me? If not, ignore it. If so, update CLASS database.

Run CLASS with current information on shop and MRP status.

**Figure 7:** Updating the CLASS database in real time.
References


