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Green MRP: identifying the material and environmental impacts of production schedules

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Interest in environmentally responsible manufacturing has increased in recent times. However, this attention has focused primarily on the design activities of the firm. Largely overlooked have been the planning/scheduling activities of manufacturing. This paper introduces a new tool that integrates environmental concerns into the material planning activities and identifies the waste streams generated in both quantitative and financial terms. This approach should be interesting to practitioners and researchers in that it is based on the widely used MRP processing logic. This new approach is called Green MRP. Examining the feasibility and effectiveness of this procedure, the research presented draws on production data for a taillight assembly produced by an American automobile manufacturer. The results show this approach is not only feasible but also has great potential

1. Introduction

Environmental issues are becoming increasingly important to manufacturing managers, their employees, investors and researchers. Contributing to this importance are governmental regulations, international certification standards (most notably ISO 14000) (Daniels 2000), and changing consumer demands. Playing a major role as well is the acceptance of developments such as Just-in-Time and Total Quality Management. Because these developments focus on the identification and elimination of waste, they force managers to deal with pollution as a form of waste (Porter and van der Linde 1995a, b). Consequently, managers are being pressured from all sides to produce more quickly better and less expensive goods in such a way as to generate less waste during production, storage, usage and disposal.

Paradoxically, however, manufacturing managers are not responding to this challenge by adopting environmentally responsible manufacturing systems. Even in the face of a growing number of positive and negative sanctions, most resort to end-of-pipe solutions (those that deal with pollution after it has been created) instead of implementing proactive solutions to pollution (those that focus on underlying

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causes). Why? First, many do not realize the true cost of waste in each phase of the manufacturing process (design, planning, scheduling, execution). Second, even managers inclined to act on environmental concerns cannot find analytical tools to help them identify waste, convert it into monetary terms and eliminate it through the implementation of specific proactive measures. The purpose of this research is to give managers just such a tool—Green MRP.

The need for this research is indicated by the failure of past studies of Environmentally Responsible Manufacturing (ERM) to include examination of the critical roles of manufacturing planning, scheduling and execution systems. Up to this point, most ERM research attention has been focused on product/process design (Allenby 1993, Fiksel 1996, Sroufe *et al.* 2000). This is not to suggest, of course, that this myopic approach has not been taken without good reason. After all, decisions made during the design stage have significant impact on design performance (Fabrycky 1987, Ulrich and Pearson 1993).

This focus on product/process design, however, has overlooked reasons why researchers should go beyond design and investigate the benefits of planning. First, planning, scheduling and simulation activities reflect the strategy and policies of the firm. That is, all decisions made by various personnel in the firm ultimately become evident in simulation, or once production is scheduled. Second, corrective action becomes more costly after order release. Finally, the analytical tools that have emerged from product/process design research have limited applicability to planning, scheduling, and execution systems. For example, these tools include such procedures as Life Cycle Analysis (LCA), Design for the Environment (DfE), screening methods and risk analysis (Fiskel 1996), which are not well understood by targeted users and not integrated into the critical systems of most firms. In other words, these tools are different from those used by designers and schedulers, i.e. the personnel primarily responsible for managing the manufacturing system. This means that a planner must use one set of tools and procedures for planning production and a separate set for assessing the environmental impact of the resulting schedules, which increases both the level of planning complexity and resulting lead times. Therefore, what is needed is one tool that integrates planning, scheduling and execution within an existing simulation framework familiar to targeted users.

This paper aims to remedy these oversights by introducing Green MRP, a single tool that targets the operational planning subsystem. This tool is essentially a conventional Material Requirements Planning (MRP) system that has been modified to include environmental considerations when converting the Master Production Schedule into the various component schedules. Through this inclusion, Green MRP solves the problem of minimizing environmental impact when managing industrial waste, by flagging potential component planning and environmentally related problems. Just as importantly, this system can convert these environmental impacts into monetary terms.

Using a case study approach, this research investigates the feasibility of Green MRP focusing on the material planning, scheduling, and execution. This research involves the use of an existing product, a taillight assembly, within an automotive manufacturing facility. The explication of this case based research and results are organized as follows. Section 2 describes in more detail the research objectives and design. The alternative approaches to the design of the Green MRP system, the prototype part and data collection are then discussed in Section 3. The results are presented in Section 4. Finally, Sections 5–7 discuss the findings and limitations of the research and contain suggestions for future research in this field.

2. Research objectives and obstacles

A successful environmental tool must satisfy certain general objectives. First, the tool must be easily understood. This first objective is based on the user dictum initially proposed by Gene Woolsey (Melnyk and Denzler 1996: 885): 'A user would rather live with a problem that they can see, than use a solution that they cannot understand.' Second, a successful ERM-related tool must recognize that the critical task for the users is not improved environmental performance (that is a secondary benefit), but better products, processes and schedules. Anything that does not directly support these activities or contribute to the ability of the users to achieve these objectives will be considered only after the critical tasks are achieved. Third, the impact of ERM-related changes and problems must be stated in terms meaningful to the user and related to the manner in which performance is monitored and assessed. Managers are driven by the measures used to evaluate performance. As Oliver Wight, a well-known manufacturing consultant, often noted, 'You get what you inspect, not what you expect.' Fourth, the ERM tool must be integrated into the core activities of the firm. Finally, the ERM tool needs to capture new metrics in the form of dimensions and types of waste.

Meeting the proposed objectives and integrating environmental waste streams into the MRP planning logic involves many obstacles. First, in selecting MRP as the vehicle, it must be realised that traditional MRP logic cannot deal with the capacity implications of environmental waste. This reduces the overall effectiveness of this approach. Second, in introducing this environmental dimension of performance, it is not realistic to reprogram the MRP logic from the 'ground up' to incorporate these features. Rather, it is more realistic to implement Green MRP as an additional functionality to an existing MRP system. The procedure would be most attractive if it were to be presented as an additional functionality that builds on the MRP logic with which most managers are familiar. Third, 'what-if' analysis had to be stressed (Lunn and Neff 1992). One of the major advantages offered by any MRP system is its ability to simulate. This 'what-if' capability is critical because it enables the user to identify and understand the various interrelationships that exist within the planning/scheduling system. Finally, the monetary dimensions of environmental waste had to be stressed. This dimension enables the user to deal with the various quantities in which waste is generated and reported.

The final obstacle of Green MRP development and testing is one of comprehensively capturing information about the many types of manufacturing waste. Researchers need to understand better the types of waste present in a manufacturing setting and how these various types of waste impact planning systems. The dimensions and types of waste impact more than just disposal costs and can be used for the evaluation of the proposed Green MRP system.

As shown in table 1, environmental waste is a multifaceted concept in which one can identify at least four dimensions: (1) source, (2) presence of intermediate storage, (3) disposal and (4) impact. These four dimensions are important because they enable the researchers to identify and describe the various critical categories of environmental waste. These dimensions also influence the treatment and modelling of environmental waste. Further, the dimensions form standards against which one can evaluate the effectiveness of any procedure or tool. It can be argued, for example,

Sources(s)	Storage	Disposal	Impact
Production waste	immediate disposal	salvage	type
Operation waste	temporary	preprocessing	quantity
Process waste		disposal	timing
Scrap			capacity
			monetary

Table 1. Nature of environmental waste.

that the more environmental waste categories encompassed by a proposed procedure, the 'better' that procedure. While there may be infinite kinds of waste, the purpose of this discussion is not to identify and define each. Instead, the dimensions and types of waste identified are used to uncover the dynamic and complex setting in which a Green MRP system operates.

2.1. *Source*

The first environmental waste dimension describes where in the production process the waste stream is encountered. Waste streams have at least four primary sources: pollution, production waste, operations waste, process waste and scrap.

2.2. *Presence of intermediate storage*

After understanding where environmental waste is created, there tends to be two general outcomes for environmental waste. The first is that the waste is immediately disposed, e.g. gas is vented into the atmosphere. Alternatively, waste is stored pending its subsequent disposal. Whether it is stored is a function of the practices in the firm. Typically, this is a temporary activity and, ultimately, the items must be disposed of in some manner (be it landfill, reprocessing or remanufacturing). The relief of this intermediate storage can be done in two ways. It can be time- or quantity-based.

2.3. *Disposal*

This dimension of environmental waste addresses the issue of what happens to the waste when it comes time to remove it. Management has the following options available to it; salvage, reprocessing and disposal. Typically, there is no management intervention unless the disposal causes the firm to be out of compliance with existing governmental regulations.

2.4. *Impact*

The last dimension describes how environmental waste affects the firm and its operations. There are at least five major forms of impact: type (e.g. hazardous, non-hazardous), quantity, timing, capacity and monetary

When these four dimensions are combined, the firm's planning system is faced by 120 categories of environmental waste (four types of source * two types of presence of intermediate storage * three forms of disposal * five types of impacts). Based on the experiences of the research team with numerous systems and their management of the waste streams, it is fair to say that few firms have information about these varied categories. It is against these various categories of environmental waste that any new proposed procedure such as Green MRP must be evaluated for its comprehensiveness. The development of a comprehensive system is only one objective of this research. A critical part of obtaining this objective, it to first understand and agree to the mechanism used for the Green MRP system.

Great difficulty surrounded the early development of the specific mechanism and approach used in modelling the environmental impacts of a given schedule, the existing bills of materials and the processes. This challenge involved more than simply the issues of mechanics but also the information database needed to support the operation of these mechanisms. To that end, three procedures for integrating these issues into the MRP logic are next discussed.

3. Methodology

3.1. *Competing approaches to the development of Green MRP*

In developing the prototype, a multimethod approach was first assessed, and then applied. The first method developed was the 'Modified BOM Approach'. In this proposed method, the BOM would include all the waste products generated at each level. The component inputs are denoted as positive quantities (flows in), while the waste streams produced are indicated using negative quantities (flows out). The timing of waste streams would be dependent on the timing convention. That is, waste could be produced equally over the appropriate lead-time or it can be made available at the end of the lead-time. This approach had the advantage of being very intuitive and easy to understand. It essentially took the bill of materials structure and added to it the waste quantities at the appropriate levels in the bill. If the user understood the concept of the bills of material, then they could understand the modified bills structure. Further, this approach would greatly increase the visibility of waste issues, as many of the standard screens and reports of the MRP system would now display waste information.

Implementing this approach would be a major undertaking. In many cases, it would require major changes in conventional MRP systems. Intuitively, the size of the BOMs would increase, so additional computer storage might be needed. It would also require that every bill be reformulated to include this additional information - not a minor undertaking. Also, for this approach to be user-friendly, it would be helpful if the MRP system would tie each waste (e.g. the excess plastic used in a moulding process) with the part that it is associated with (e.g. a completed plastic body). This feature is not currently found in MRP systems, and it would take substantial programming effort for such a 'tying' function to be created.

A second way of capturing waste information would be to create a '*Bill of Waste*' (BOW), parallel to each and every current BOM in the MRP system. This BOW would contain the waste information associated with its parallel BOM. This approach is similar to the Bills of Labour and the Bills of Resources used within many firms for the purposes of planning capacity and resource implications of various schedules. While this approach does not link the waste streams to the components in as close a relationship as found in the 'Modified BOM' approach, the BOW approach would still take advantage of the standard screens and reports available in current software. There are two major problems with this approach. The first is that it would require a new bill structure to be set up within the MRP system. At present, no MRP system has a bill of waste incorporated into its structure. Introducing such a feature would be a major programming logic change for current systems. The BOW approach would require the computer program to manage the links between the BOMs and BOWs. While the introduction of this structure may occur sometime in the future, it is not feasible with current systems. An additional problem is that it is very data-intensive. Populating the BOW with data would require most firms to collect complete waste information, much of which they currently lack.

The third approach considered is the '*Scrap Factor*' approach. This approach uses the existing scrap factor functionality found in most MRP software to track the types of waste created. The primary advantage of this approach is that it requires the least amount of change in both the understanding that managers have of their MRP system (and its inputs and outputs), and the MRP software itself. Thus, existing screens and reports can be used. While simplistic in its treatment of environmental waste, this approach offers users the ability to demonstrate and evaluate the potential of the 'Green MRP' logic. Further, it enables the system to capture easily at least three of the four sources of waste (scrap, processing, operation). It also can capture the quantity, timing, type and, with modification, the monetary impacts of environmental waste. The primary limitation of this approach is that it cannot easily deal with waste streams that are stored in an intermediate inventory. It also has difficulty in dealing with the salvage and reprocessing disposal options. However, in spite of these limitations, this option was selected because it was feasible and consistent with the objectives of this study. In addition, its use recognized that many users tend to be risk adverse when dealing with ERM tools and issues. They want systems that introduce the fewest changes to their current practices and procedures.

3.2. *Prototype development*

One of the objectives for this prototype was to demonstrate the feasibility of the Green MRP system and to subsequently evaluate the viability and utility of this procedure within an actual manufacturing environment. A major American automotive manufacturer assisted the research team at this stage of the project. The management of this firm identified a manufacturing plant to act as the test site; they also actively and visible championed this research project, which was critical in securing plant management participation. The prototype was developed through a process consisting of three stages: (1) identifying the part to serve as the test bed, (2) data collection and (3) creating the Green MRP system.

3.2.1. *Identifying the test bed part.*

From the outset, the researchers, in consultation with representatives from the industrial partners, determined that the 'ideal' product selected for this study had to meet the following requirements.

- Simple structure: the ideal product was defined as one having five or fewer levels in the bill of materials and no more than 15 components or subassemblies. Simple structures allowed the researchers to focus attention on developing and debugging the Green MRP system, rather than on data collection.
- Combination of purchased and manufactured components: such traits allowed the researchers to evaluate the environmental impact of these two types of components.
- Environmental problems and opportunities were present: these problems and opportunities allowed the researchers to identify and quantify the problems and to assess the opportunities for improvement. Further, these opportunities had to extend beyond the common options of reduce, reuse and recycle.

- The effects and alternatives could be considered from a cost perspective: this requirement was necessary so that the researchers could present management with a compelling reason for change, thus encouraging them to 'buy in'.

Using these criteria, a truck taillight assembly was ultimately selected. (There is no picture of this taillight assembly provided. If provided, the picture would clearly identify the truck brand and the identity of the industrial partner.) This product was fabricated within a wholly owned plant located in Ohio. It has a short lead time, with production required < 8 h, that used a mixture of purchased parts as well as internally manufactured parts. It also had both a relatively simple product structure and a simple process flow (figure 1). Further, the assembly contained a great deal of plastic, which was of great interest from an environmental perspective.

This part had numerous environmentally related options and opportunities. For example, the backplate for the taillight could be made either from virgin Acrylonitrile Butadiene Styrene (ABS), recycled ABS or a combination of the two. In making the back plate, a gate or spur was created. This gate accounted for between 10 and 20% of the total ABS used to produce the back plate. When removed, the gate was placed in a bin, which was then used as input to other products made by the plant. Scrap identified at the end of the process could be either landfilled or reprocessed. Other waste streams encountered included recycled material, waste vented into the air, processing waste and landfill. Finally, the environmental costs were hidden because the costs assigned to each finished product reflected not only the direct costs associated with making that item, but also the waste streams created. For example, the spur created when moulding the back plate was assigned back to the taillight, as if it were never created in the first place.

3.2.2. *Data collection*

Initially it was expected that there would be few problems, if any, in collecting the necessary information. The plant was an experienced MRP user. In addition, it had

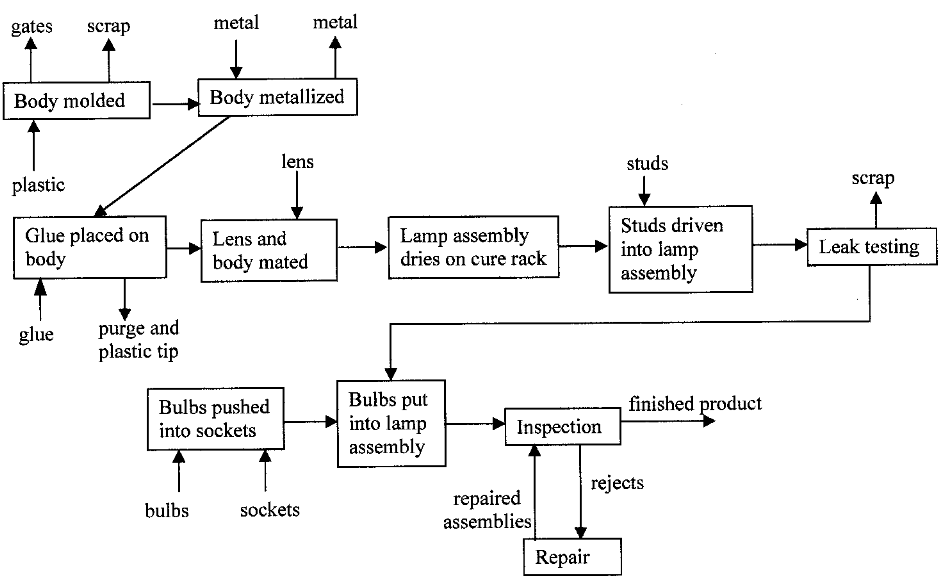

Figure 1. Taillight assembly – process flow.

an excellent record in collecting and reporting the information required by the Environmental Protection Agency (EPA). Yet in practice, the researchers found that this stage required more time than was initially estimated. Ultimately, the required data was collected by a combination of direct observation at site visits, use of routing and bills of material information, use of monthly reports on collected scrap, and discussions with personnel directly involved with the processes and components being studied. In the process of collecting this information, two interesting observations were noted. The first was that much of the critical environmentally related information was not formally tracked or recorded. In addition, there was a great deal of disagreement about the size of the environmental waste streams. For example, after the back plate was moulded, it was sent to a station where it was metallized. This task involved taking metal and then spraying it onto the back plate. However, not all of the material sprayed made it to the back plate. Some landed on the surrounding fixtures, some was vented into the air. The researchers could not determine the percentage of metal that was successfully applied to the back plate and the percentage that was lost. In many cases, asking two different people about this percentage resulted in two different estimates, both of which were strongly supported. The second observation was that the primary metrics for evaluating shop performance were on-time performance and cost. This was important because it helped the research team understand what Green MRP metrics the firm would find most useful.

Once the data were collected, it had to be converted into a form suitable for the MRP system. A problem encountered at this stage was that of how to deal with those situations where information was either missing or subject to considerable disagreement. For the first case, a conservative 'best estimate' was used based on input from the users. For the second case, using guidelines provided by Law and Kelton (1991) for building simulations in similar situations, triangular distributions were used for generating information. These distributions were anchored using pessimistic and optimistic values for the ends of the distribution and the mode value.

3.2.3. *Creating the Green MRP system*

With this data, the next stage was to implement and run the prototype Green MRP system. MAGI of Grand Rapids provided the MRP software. This package was selected for several reasons. First, several plants operated by the industrial partner used it. Second, it is considered to be a complete and consistent application of conventional MRP logic. Third, the software vendor was interested in working with the researchers and had provided the researchers with a copy of the program and with access to programmers. This was needed since several changes were required within the program to facilitate the operation of the Green MRP logic.

To make the runs as 'realistic' as possible, actual production data and practices were used in developing and running the model. Since production was scheduled on a daily basis and since all orders released were completed within the day, a daily time bucket was used within the MRP system. The practice within this line was to try to level production at 3600 'good' taillight assemblies per day. As a result, the master production schedule driving the Green MRP system was set at 3600 end items per day. Furthermore, waste was generated at several specific points in the processing. Specifically, these included: (1) metallization of the backplate (where not all of the metal coating sprayed on the backplate reached the backplate); (2) gate production during moulding of the backplate; (3) rejects created during mating of the lens to the backplate; (4) operations waste (in forms of the periodic purging of glue nozzles at the lens mating operation); (5) bulb rejections; and (6) entire assembly rejections. These were included in the base runs of the Green MRP to determine and assess the 'as is' conditions. In addition, in assigning values to represent these various environmental problems, care was taken to ensure that the values used in the Green MRP system were well supported and that they were set conservatively. As will be shown in the results, the data collection yielded very accurate information regarding the costs and amounts of waste produced from the process and product used in the prototype.

4. Results

Several different scenarios were run using the Green MRP system. These included: (1) the base case, with all waste streams are present, which was used to validate and verify the model; (2) no waste; and (3) various combinations of environmental waste levels (to reflect various actions that management could take). Two of these runs are summarized below. These two runs consist of the extreme points on the environmental waste continuum.

Working with the firm, the researchers were able to produce a product cost worksheet. The worksheets generated used the scrap factors for the parts and for the routings. These worksheets allowed the cost of the scrap to appear on reports that a planner could generate before the order was released to the shop floor. This allowed for an 'up-front' or forecasted look at the potential environmental wastes generated before any real problems occurred. This also allowed for better planning for waste disposal, understanding of where the costs of the waste are coming from, and what processes or products need to be further developed to minimize their impact on the waste stream.

Most dramatically, these worksheets illustrated the costs of waste. Using a simple 'what-if' analysis, the research team generated product costs for the part 'as-is' and for the part assuming that all waste had been eliminated from the production process. The results of these two reports, both generated by the resulting Green MRP system, generated a cost of US$10.727 for the 'as is' scenario, and $10.414 for the 'no waste' scenario. A comparison between the two scenarios shows a difference of about $281,700 when summed over a year's worth of production (assuming one shift per day of production). This number was arrived at by taking the difference in costs due to environmental waste ($0.313 per piece) and multiplying it by the number of units produced per year (assuming production of 5 days per week and 50 production weeks). By explicitly recognizing the cost of environmental waste in this way, the researchers were able to decompose a part of the overhead and take out of overhead that component attributable to environmental waste. In the process, the environmental problem, previously hidden in overhead, became more visible. The type of possible cost savings uncovered by the Green MRP system becomes even more dramatic when it is considered that this was only one part of a truck that contains thousands of parts.

4.1. *Assessing the Green MRP system*

The previous discussion demonstrates that Green MRP is both feasible and able to identify the environmental waste streams generated by a given schedule, product structure, and processing system. Assessing the effectiveness and efficiency of Green MRP requires an examination of three performance dimensions. The first is of comprehensiveness. As previously pointed out, there are 120 different categories of environmental waste. Green MRP can deal with about 54 categories of these 120. That is, Green MRP can deal with three of the four sources of wastes (it cannot deal with preproduction waste). It can also deal with settings where intermediate is both present or absent. It can deal with all three forms off disposal and four of the five impacts (everything except capacity).

The second performance dimension is that of how well the Green MRP captured the costs, as reported within the plant's accounting system. On this dimension, the researchers began from a point where they did not have access to all of the cost data for the test bed part. However, after the completion of the base run, the participants from the industrial partner, in reviewing the results, observed that the calculated costs from the Green MRP reports were within 5% of the cost standard for this part. They were amazed that the system could perform that well.

The next dimension assessed is that of user acceptance. To this end, the researchers presented the new system to a group of managers at the subject company. The presentation included a discussion of some ERM concepts, and a description of the research project. The results of the Green MRP system were presented and discussed. This included a discussion of the various simulations, or 'what-if analyses' performed. After the presentation, the researchers distributed a survey for the purposes of gathering feedback from the management team on the viability of Green MRP. Five managers from various functional areas (the mean results are presented in figure 2) completed this survey.

The results presented in this figure 2 underlie certain trends. The first is that there was acceptance among the managers for the Green MRP approach and its usefulness in dealing with environmental wastes. The second was that there was only mild support for the need to reduce waste as a way of improving performance and of improving value to the customers. Finally, the managers did not see the need for a Green MRP system because they did not see pollution as a problem at their facility. This position was in spite of being shown the magnitude of the environmental impact on production. In short, while the procedure was feasible and understood by the target users, the users (the managers) did not really see a compelling reason to deal with the environmental problem. In subsequent discussion, they saw environmental waste as a problem only when these problems resulted in fines from government regulators. As long as the facility was not generating fines, the facility was deemed to be performing acceptably (Sroufe *et al.* 2000).

In a discussions after the presentation, one curious idea emerged. As mentioned, the research team had some difficulty in obtaining the data on the amount of waste produced, despite full cooperation from the subject firm, and some significant investments of time and effort by the firm's employees. Despite this expenditure of effort, in some cases the research team had to use estimates for some of the taillight's production data. What emerged in the post-presentation discussion was that perhaps this information was actually being collected and stored on a much more extensive basis than the original data collection indicated. The problem appeared to be that the data was fragmented throughout the company. As an example, one person mentioned how exact counts of one particular type of material waste for this manufacturing process was kept on series of paper reports sent to the government.

Question	Mean response (0 = strongly disagree, 10 = strongly agree)
Control of waste and pollution is very important at this facility	9.8
Control of waste and pollution is monitored at this facility	9.6
I understand the MRP approach to material planning	9.6
The Green MRP approach was clearly presented	9.6
I understood the logic of Green MRP	9.6
We currently use MRP as a tool for material planning and scheduling	9.4
I am/would be comfortable using the MRP approach to material planning	9.2
The values used for scrap and waste within the Green MRP system for the (taillight) example are realistic	8.8
The Green MRP system accurately identified environmental waste impacts	8.8
I would use the 'what if' capability to evaluate alternatives	8.8
The Green MRP system does a good jog of identifying the waste costs of current schedules and design	8.6
Green MRP is a useful manufacturing tool	8.6
If it were available, I would support he use of Green MRP for planning and scheduling production	8.6
I would use the 'what if ' capability to identify areas to focus on for improvement	8.4
The 'what if' capability provided by Green MRP is useful	8.2
I understand the changes made to MRP that were necessary to create a Green MRP system	8.0
Green MRP does a good job of integrating environmental and scheduling issues	8.0
Waste information for this facility is currently available to you	7.8
It would be useful if the Green MRP system provided a structured method for identifying specific areas to look at in a prioritized order	7.8
The areas of waste identified by Green MRP are ones that can be improved	7.8
Reducing product and process waste would greatly improve operations at this facility	7.0
Our customers want products that are produced in more environmentally responsible manner (e.g., through the use of more recycled material)	6.8
Reducing pollution would greatly improve operations at this facility	5.0
Control of waste and pollution is a problem at this facility	3.4

Figure 2. Management assessment of traits relevant to Green MRP.

5. Limitations of Green MRP

What issues would vitiate the Green MRP system? As with any MRP system, it is only as good as the data provided to it. Some firms may have difficulty in obtaining the detailed waste data necessary to run the Green MRP system. At first, this data collection effort may appear onerous to a firm, yet it may become the case that this type of data collection effort becomes part of a firm's Environmental Management System (EMS). As EMSs become more popular and more sophisticated, systems such as Green MRP will become more important, and the data gathering required will become a normal part of doing business.

Another roadblock to successful implementation of Green MRP is the type of MRP system a firm currently uses and that firm's ability to modify it. As discussed previously, there are a number of different ways to implement Green MRP in current MRP software. The approach chosen will dictate how much modification will have to be done to the current MRP system. If a firm's MRP system is not easy to modify, or if the firm does not have the resources available to modify it, then it may be difficult to implement Green MRP.

The quality of these system modifications will directly affect the visibility waste issues in the MRP system. For instance, the MRP system used in this study was relatively easy to change a report label to 'waste in this operation'. This appeared near the bottom of the report, where the unit costs were totalled. This placement and wording gave the issue of waste a very high visibility. Firms that have difficulty modifying their MRP system, due to lack of technical skills, lack of other resources or even internal politics, will find that Green MRP will not be able to provide the firm with this key information.

Similarly, the use of 'what-if' analysis in the Green MRP system will be affected by the functionality of the current system and the ease of modification to the system. The ability of the Green MRP system to do 'what-if' analysis is extremely important, as our research in ERM indicates that decisions regarding environmental initiatives must have sound economics behind them. What-if analysis is a very powerful analysis tool for providing the economic basis for these decisions. The Green MRP approach very clearly presented the difference between the current cost to manufacture, including all waste costs, and the manufacturing cost if all wastes could be eliminated. This type of what-if analysis provided dramatic results.

6. Concluding comments

In the visits that were conducted as part of this research study, it was noticed that the real users of environmental tools are not the members of the environmental group or department. Rather, the real users are the product and process designers and those who plan production, release work for execution and schedule work. These groups are responsible for those activities that ultimately create the output, waste, which the techniques are trying to identify and control. For example, product and process designers determine the material and processes used in building the products. They also determine the amount of energy used by the products in use and the ease with which these products can be remanufactured or recycled at the end of their life. In contrast, the schedulers and planners create the schedules that are released to the shop floor. These schedules generate waste during implementation by combining the effects of timing, with product mix, process and product design. These people can affect the waste streams generated by the manufacturing system by changing such dimensions of the schedules as the timing of work and product mix.

These users are tasked with certain primary or critical activities, such as designing products and processes and generating feasible and valid production schedules. In achieving these objectives, they draw on certain widely used and well-understood tools, such as Quality Function Deployment (QFD), Design for Manufacturability (DfM), project scheduling (Fine 1998), and Material Requirements Planning (MRP). It can be argued that tools that are different from these task-related tools or that are not well integrated into the major activities of the firm will be used only if there are available time and resources. Such availability may not be present in today's environment — an environment where more is demanded in less and less lead-time.

Environmental concerns are coming to play an increasingly more important role in today's world (Makower 1994). For the manufacturing managers, this means that they have been able to evaluate their actions in terms of how these actions affect lead time, cost, quality, flexibility, and now the environment. More important, managers must be able to anticipate potential environmental problems and to take appropriate corrective actions. These problems must be anticipated not only in terms of product and process design but also in terms of the schedules released to the system for execution. This study introduces a procedure, Green MRP, that builds on the traditional MRP system and extends it to identify and to communicate potential environmental problems in quantitative and monetary terms. This study has also demonstrated some of the inherit complexity when dealing with environmental wastes. It has evaluated the feasibility and effectiveness of this procedure along a number of critical dimensions. The results show that Green MRP is not only feasible but that it can also provide a useful tool that managers can use to improve the quality of their production schedules. It is hoped that the findings presented in this paper will encourage other researchers to investigate and develop empirical research in this area. More importantly, it is hoped these findings demonstrate the need for procedures, well understood by the target users, that have been modified from traditional systems so that they now address the environmental dimensions of performance.

7. Suggestions for future research

Researchers have tended to focus on developing tools and procedures that are uniquely able to capture and report the impact of potential environmental problems. A limitation of these tools, as previously noted, has been that they were well understood by the tool developers, but poorly understood by the users. Green MRP illustrates the potential offered by taking existing well known tools and procedures and modifying them so that they can now deal with environmental issues and problems. MRP is only one tool available to the production planner and the scheduler. These users take advantage of other tools such as capacity planning and scheduling, be it in the form of finite/infinite capacity planning and management or Advanced Planning and Scheduling (APS) systems. By focusing on MRP, this study has dealt primarily with the material side of planning and execution. It has ignored the capacity side. Capacity is critical because pollution waste consumes capacity either directly (capacity used to generate pollution is not used to generate 'good' products) and indirectly (the capacity required to store pollution by-products). In addition, it is possible to conceive of legally imposed constraints on the amount of pollution that can be produced in any given time period as a form of capacity. As a result, the researchers envision great potential in extending the Green MRP approach to other tools and areas of planning and scheduling, such as capacity planning.

The research findings presented in this study, while specific to one firm and one plant, indicate that the organization and availability of information is a major obstacle to the successful implementation of the Green MRP approach. Information is critical not only procedures such as Green MRP but also to existing environmental procedures such risk analysis and Life Cycle Analysis. Without the 'right' information and data, these procedures cannot be expected to work correctly. In the plant used for evaluating the Green MRP prototype, the necessary information was scattered across many departments and functions. Given the importance of data and information to procedures such as Green MRP, it is important that attention be directed towards assessing the degree to which existing data collection, storage and reporting systems are consistent with the requirements of various environmentally related procedures, such as Green MRP, Life Cycle Analysis, and even ISO 14001 certification. This type of an assessment should be span numerous plants and industries. It is necessary so that researchers can understand the nature of existing data collection procedures, as they pertain to environmental initiatives, and be able to identify the constraints and obstacles imposed by such procedures. By focusing on this issue of data collection, researchers and practitioners can identify how data should be collected in advance before it is stored, so that it is most useful to various environmentally related tools and procedures. Many past studies have assumed that the data would be available in the 'correct' format. The experiences at the plant studied in the paper indicate that this assumption is not realistic. What results, is the need to better understand the information systems' aspects of the problem.

Another important area for future research deals with the notion of a compelling reason for change. Initially, when approaching the task of reporting the impact of pollution and motivating managerial action, the researchers had assumed that managers would be motivated to change the behaviour of the underlying processes, should they be presented with quantitative-based evidence of the impact of pollution, presented in dollar terms. In spite of the size of the costs associated with pollution, the managers were not motivated to change. This raises an interesting but unresolved question - what constitutes a compelling reason for change and under what conditions? This is a critical issue because the ultimate intent of procedures such as Green MRP is not simply to report pollution in advance. Rather, it is to make managers aware of the pollution effects associated with a given schedule. It is also to trigger action, such as changing the schedule. It would be insightful if researchers could understand how to trigger change in such groups as innovators, early adopters and early majority (Moore 1991, Sroufe *et al.* 2000).

A fourth direction for future research would be to analyse whether the Green MRP approach is consistent with new developments such as ERP and ISO 14000. It would also be interesting to note the extent to which these various developments are consistent with each other (e.g. the extent to which ISO 14000 certification is consistent with either Green MRP or ERP). If inconsistent, than unforeseen obstacles to implementation may be encountered. Such obstacles force managers to view these initiatives as trade-offs, rather than as complements. These issues have yet to be explored.

Finally, procedures such Green MRP can be viewed as potentially complicating the scheduling and planning processes. Given the increasing emphasis that has been placed on reducing lead times and in better responding to changing conditions, this raises the issue of the extent to which environmental initiatives are really consistent with lead time reduction. Gaining acceptance of procedures such as Green MRP and Life Cycle Analysis requires convincing the target users that the benefits gained by the use of the procedures outweighs any costs.

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