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Integration of Network Analysis Systems With MRP in a Make-to-Order Manufacturing Environment

by

G. Harhalakis and S. Yang

INTEGRATION OF NETWORK ANALYSIS SYSTEMS WITH MRP IN A MAKE TO ORDER MANUFACTURING ENVIRONMENT

George Harhalakis*

Department of Mechanical Engineering
and Systems Research Center
University of Maryland, College Park, MD 20742

Susan Yang**

Department of Mechanical Engineering
University of Maryland, College Park, MD 20742

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Authors : Dr. George Harhalakis[1] and Ms. Susan S. Yang[2]

ABSTRACT

The unique requirements in a make-to-order manufacturing environment dealing with long lead time products cannot be satisfied by either MRP or Network Analysis systems alone, but necessitate a combination of features of both. MRP is capable of handling manufacturing tasks in great detail, but it is not designed to accommodate non-material related tasks. Further, schedules generated by MRP do not reflect the flexibility desired in varying amounts in every manufacturing contract. On the other hand, Network Analysis, else known as Critical Path, can handle activities of any nature. It provides flexibility in scheduling activity and caters for resource and cash flow scheduling and other features usually not present in MRP systems.

The paper examines the above issues in detail and describes an integrated MRP/Network Analysis system for use in a make-to-order manufacturing environment by demonstrating potential benefits on purchasing and manufacturing orders generated by a combined MRP/Network Analysis system compared to ones generated by traditional MRP systems. A computer program is being developed to implement the above issues and this paper contains portions of the program.

1. Systems Research Center
(301) 454-8943
2. Department of Mechanical Engineering
(301) 454-1480

University of Maryland
College Park, Maryland 20742
U.S.A.

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INTRODUCTION

The unique requirements of the make-to-order manufacturing environment have been neglected in the rush to develop and implement software tools for better operations management. Make-to-order manufacture, which is characterized by highly sophisticated products, very small lot sizes (typically one), long lead times and high levels of customization and customer interaction, lies somewhere in the region between job shop manufacturing and project work. Accordingly, software systems developed for these two applications, like Material Requirements Planning (MRP) and Network Analysis systems such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), respectively, are only partially suited to the make-to-order manufacturing environment.

MRP primarily aims at improving the production and inventory management functions of manufacturing by providing a time phased material plan for a required production schedule. MRP promises such improvements as lower inventories, reduced delivery times, higher stock-turn ratio and improved customer satisfaction. While MRP in its present form is largely adequate for the tasks involved in batch manufacturing, several shortcomings become apparent when it is applied to a make-to-order manufacturing environment. Chief among these shortcomings is the lack of two way time analysis during scheduling. MRP performs only a backward time pass, beginning at the level of the end product and working backward through the Bill of Material (BOM) structure, which results in a schedule comprising only of so-called "late times" (i.e. the latest possible times at which events must occur in order to meet the required end product delivery date). Another shortcoming is presented by the structual restrictions in the BOM for MRP analysis. Elements in the BOM must have a material content and must be arranged so that the structure only explodes downward from the end product; upward explosion is prohibited.

These restrictions prevent the applicability of MRP in cases where long lead times and a high degree of uncertainty make a two way time analysis beneficial, if not essential. Further, the extensive customer interfacing and other non-material related activities, including pre- and post-manufacturing tasks involved in custom-made products, cannot be scheduled by MRP or included in the BOM structure. Other typical make-to-order type of activities, such as temporary assembly, testing and subsequent break-down of assemblies for further processing, likewise violate the BOM format because they require upward explosions.

Project planning/scheduling, by a form of Network Analysis such as CPM or PERT, is far more flexible in both of the above issues. These technique, unlike MRP, utilize a two-way time analysis which produces both "early" and "late" times for activities and identifies the activities that are critical to the project versus those that have some slack time. Further, the project network, which like the BOM in MRP, functions as the foundation of the system and has a much less restricted structure than a BOM. Elements in the network represent activities, which may or may not have materials, resources and costs associated with them. In addition, links between activities may occur in any logical arrangement, providing for the less common relationships, occasionally encountered in make-to-order operations. However, a Network Analysis system does not provide the production and inventory management capabilities of MRP. Therefore, Network Analysis is unacceptable as the sole controlling system in a make-to-order manufacturing environment.

The unique requirements in a make-to-order manufacturing environment necessitate a combination of features of both MRP and Network Analysis systems. In spite of the large number of operations where such a system could be used (e.g. Department of Defense contracts, large equipment manufacturing, and so on), it appears that little research has been done in this area. The idea of combining CPM and MRP has been presented in the literature [1,8,9], but in these cases it is described in the context of project work (i.e. incorporating MRP logic into Network Analysis) rather than in the context of manufacturing. Further, these strategies fail to achieve the full benefit of integration of both features because the approach of each is to transform the much more flexible network structure into a more restrictive BOM. The few apparent discussions of a combined MRP/Network Analysis system applied to manufacturing [5,6] have not been explicit enough, nor detailed and implemented to an appropriate extent.

In this paper, the similarities and differences between MRP and Network Analysis systems are outlined. The structure of a integrated MRP/Network Analysis system is described. In addition,the application of an integrated MRP/Network Analysis system for use in a make-to-order manufacturing environment is presented by demonstrating potential benefits on purchasing and manufacturing orders generated by the combined MRP/Network Analysis system, compared to ones generated by traditional MRP systems. This paper finally contains portions of a computer program which is being developed to implement the above system.

THE STRUCTURES OF MRP AND NETWORK ANALYSIS SYSTEMS

The fundamental structure of both MRP and Network Analysis is a combination of static and dynamic elements. Within MRP, the static element is the BOM which serves to answer the question "what is to be made". The dynamic component of MRP includes the backward time analysis and provision of resources through inventory control, purchasing orders and manufacturing orders. The dynamic component answers "when", "how many" and "how" to undertake the individual tasks required in order to achieve the fulfillment of the overall manufacturing plan. Similarly, Network Analysis is comprised of static and dynamic components. The static component is the geometry of the project network, which depicts "what" is to be done. The dynamic component consists of both the two-way time analysis and the resource allocation/scheduling, which similar to the dynamic component of MRP, determines "when" and "how" to proceed to best meet the goals of the project. Given the fundamental similarities in the constitution of the two systems, the feasibility of combining the features of each into a single system becomes clear.

Material Requirements Planning (MRP)

The success of an MRP system if largely dependent on a properly constructed Bill of Materials (BOM), which defines the product structure. But within the structure of the BOM lie several weaknesses that limit the application of MRP in a make-to-order manufacturing environment. A BOM is a hierarchical structure defining and relating the components of each assembly and subassembly of a product [7]. The links indicate a sense of belonging (i.e. a parent-child relationship) ; components at a given level in the BOM "belong" to their respective parents in the next higher level. Such notation depicts the assembly of components and raw materials into higher level assemblies or subassemblies. Each element in a BOM represents a physical material or component. The activities necessary to create each element, such as purchasing, assembling or machining, are implied by the links between elements and their "children". The time required to perform the activity is reflected in the lead time given to that element. Thus a BOM element always has a material content associated with it and will generally have an implicit work content as well.

In a make-to-order environment there are usually many important activities not directly associated with the fabrication, assembly or the processing of a specific item such as activities with work content but no material content. Such activities often occur in pre- or post-manufacturing phases of a contract and may include marketing, estimating, product engineering, production control, erection and commissioning. In fact manufacturing activities may represent only a small portion of the entire contract cycle in some industries. Hence, by using MRP alone a substantial portion of the contract work content cannot be represented in the BOM and therefore cannot be controlled.

A second weakness in a BOM structure is its hierarchical format. A typical BOM is pyramidal in shape with explosions allowed only downward; an element may have more than one component, or child, but no elements can have more than one parent unless duplicates of the element appear in other locations in the same BOM. A practical application in which multiple parents are required is in the event that components are temporarily assembled for testing before final machining or other finishing processes can be applied. After testing, the assembly is disassembled and the individual parts completed before final assembly. Attempting to enter the indicated relationship into an MRP system would either result in an immediate error or, if not caught by the system checks, the MRP logic would duplicate the requirements for the temporary assembly since it is the child of two parents.

Another weakness of the BOM structure is the restriction of the links between elements to "finish to start" relationships. An activity cannot start until all those preceding ones have been completed. More flexibility would be obtained if it were possible to define relationships between activities which should be allowed to overlap each other and those which must be separated by a time delay or lag. Since make-to-order products are typically highly sophisticated and involve large numbers of components and activities, this added flexibility is certainly desirable.

The timing process of MRP similarly has its shortcomings. The major deficiency is the lack of a two way time analysis during scheduling. MRP logic begins with the due date of the end product and works downward through the BOM structure, using the lead times of each element to assign due dates for each. The resulting time schedule is comprised of the latest dates at which each component or assembly must be available and ready for use in the next higher level of the BOM. This approach is dictated by the ultimate objective of MRP which is to minimize the time that inventory and work-in-process items are present. If however, there is any delay such that any of these components or assemblies is not available until after its scheduled date, the end product will be delayed as well. This is something encountered in practice very frequently and the result is a number of costly rescheduling iterations aiming to reduce the length on subsequent work items to make up for some of these delays. Using the terminology of project scheduling, all elements in a BOM are scheduled as critical activities. No attempt is made to determine the amount of extra time or slack that may be available to some of the components/assemblies without affecting the overall project schedule. Given the length of time and the number of components/activities involved in a typical make-to-order product, this approach is obviously not practical.

One of the biggest strengths of MRP which is desired and fully applicable in a make-to-order manufacturing environment is the integration of scheduling, inventory control and purchasing functions. As MRP explodes the BOM to perform scheduling, it also checks inventory records and pending orders for the components, raw materials and purchased items required to complete each element. Gross requirement are compared with quantities on-hand or on-order to produce the net requirements to meet the production schedule. For purchased materials and components, the purchasing department is alerted so that these meterials may be ordered at the proper time. These functions are highly desirable in the integrated MRP/Network Analysis system.

Network Analysis

The two most popular forms of Network Analysis, CPM and PERT, developed in the late 1950's and early 1960's, were designed to aid in the planning, scheduling and control of large scale projects. Both are centered around the "project structure" represented by the project network of tasks which depicts the activities involved and how they depend on each other in terms of sequence and inter-relationship. Two basic network structures are commonly used, activity on arrow and activity on node. The latter also known as precedence networks were developed in the early 1960's and provide more flexible structures. In a precedence network, activities or work items are placed in boxes and linked by dependence lines which define the logical predecessors and successors of each. Further, precedence networks allow for the linking of activities whose start and finish times are not coincident with the starts and finishes of their immediate predecessors and successors; activities may overlap each other or may be separated by a lag (i.e. time delay). Figure 1 displays the three different types of relationships available in precedence networks [2]; a fourth type of relationship "start to finish" is equivalent to a "finish to start" arrangement if the two related activities are put in reverse order.

Unlike an element in a BOM, an activity in a precedence network may have as many predecessors and successors as necessary, thus removing the BOM pyramidal constraint. Each activity must have a work content and may have a material content, a resource content and a cost content as well. A precedence network can therefore be used to represent the entire spectrum of activities for a contract. One final advantage of the precedence network is that it lends itself to the identification of each work item by project or contract number. This is a useful feature given the customization required in a make-to-order manufacturing environment. For these reasons, the precedence network structure is clearly superior to the traditional BOM structure in a make-to-order manufacturing environment.

The scheduling, or dynamic element of Network Analysis, is also superior to that of MRP. In addition to performing a backward time analysis which results in the latest possible dates for each activity, Network Analysis also involves a forward time analysis which begins at the start of the network and produces the earliest dates at which each activity is allowed to start, subject to logistical constraints (e.g. availability of resources) and the completion of preceding activities. With both "early" and "late" times for each activity, it is possible to determine the amount of slack time available to each activity. The total slack time, or total float, for each activity is calculated as the late finish time minus the early start time minus the duration of the activity. If the starting time of an activity is delayed, the overall project is not affected as long as the activity is started by the late starting time. Total float may belong to an individual activity or may be shared among several activities on the same path. The free float for an activity, if present, can be used without affecting any other activities. In any project there will be one or more longest (i.e. critical) paths through the network diagram which is comprised of critical activities. Any delay in the start of a critical activity will delay the completion of the project unless future activities can be shortened to compensate for the dalay. Knowing which activities are critical and which are not allows for the best use of resources so that the project can be completed as planned.

Network Analysis also provides several tools for the dynamic control of projects. Using the early and late planning times generated by the two way time analysis, a bar chart can be created, graphically depicting the planned times and available float for each activity. Resource aggregation and scheduling are also facilitated by comparing the resources required during the course of a project to those available so that one can modify the planned times by generating fixed scheduled times that are realistic with regard to resource utilization. To minimize the effect on the overall project, scheduling takes advantage of floats wherever possible. The effect of extending an activity beyond its float to adjust the resource requirements is immediately indicated. Cash can be treated as a storable resource such that the schdule can be adjusted to reduce the cost of capital during the project. These capabilities are not available in MRP where schedules once generated are stiff even though a bar chart can still be produced in MRP without any slack time on activities. Resource requirements in MRP are not flexible either. Hence, Network Analysis provides a much more realistic schedule.

CONCEPTS OF THE INTEGRATED MRP/NETWORK ANALYSIS SYSTEM

Given the fundamental similarities between MRP and Network Analysis systems, this section is intended to illustrate the concepts of the integrated MRP/Network Analysis system. To illustrate the commonality of the "topology" or "geometry" which identifies the static element of a MRP and a Network Analysis systems, let us consider the hypothetical manufacturing BOM structure in Figure 2A which is also shown in precedence network form in Figure 2B. The product family-tree links which indicate that component items belong to their parent assembly can be seen as logical precedence links, indicating that an assembly is dependent on the availability of its components. Furthermore, the content of each box is slightly different between the two diagrams. In the BOM drawing, Figure 2A, the box marked with "Comp 1" merely depicts a part which is required to form the End Product. In the network drawing, Figure 2B, the equivalent box, possibly identified by the same part number, takes another dimension which is to indicate the action of issuing this item to manufacture prior to it being assembled or otherwise processed. Thus, the network activity marked "Comp 1" is much more comprehensive, as it encompasses an element of action, apart from merely accommodating a material content in it. Similarly, "Comp 2" is a machined part in the BOM, while in the network, the activity marked as "Comp 2" also encompasses the machining operation(s) required to change the part status from a casting to a finished part. The activity "Comp 2" has a duration equal to the machining operation time plus any set-up, movement and queueing time involved in the particular machining function. It also has a resource content and a cash flow requirement. Finally, an assembly and a subassembly in a precedence network can be seen as the action of grouping the individual parts together, in addition to the mere material content as implied in a product structure. Concentrating now on the logical links between component parts and their parent assemblies, these can be seen as typical relationship lines between activities indicating that an assembly cannot be formed until all of its components are made available, and if necessary, machined.

Once the fundamental geometrical similarities between BOM and network diagram are established, one can now enlarge the scope of BOM by encompassing a number of additional tasks, even without any material content, but with a definite work content, which are inherent in a manufacturing process. The way that MRP systems have been designed does not allow for incorporating such "non-material" elements. In Figure 3 for instance, an extra activity has been added, marked as "Test Assy C" which indicates that an in-process test is required prior to proceeding to final machining of its components and final assembly work. It must also be reminded that traditional MRP systems do not allow the situation where an activity (e.g. Test Assy C) is the child of two higher level elements. In such a case there would be an inconsistency in the system caused by the fact that two different items, 2A and 3 are made of the same "Comp C" in addition to the fact that MRP would create a dependent requirement for two C items when exploding the BOM structure. Apart form the ability to explode parts "upwards" and to introduce non-material tasks, a network-type-product structure allows for the employment of a variety of relationships between work items, such as those illustrated in Figure 1. Thus if a component is not needed immediately at the beginning of an assembly operation, it can be linked to its parent assembly with a finish to finish relationship together with some lag (e.g. "Comp 5 Motor" and "Assy A" in Figure 3). This extra flexibility has a beneficial impact on work-in-progress which can be substantially reduced.

The overall effect of all these additional possibilities offered by a precedence network diagram into which a typical product structure can be converted, is that a much more realistic and comprehensive flow chart of activities and tasks can be produced. This in turn lends itself to a number of other useful functions: resource aggregation and leveling, cash flow projections, cost calculations, simulation of hypothetical conditions by temporarily altering the logic and/or the contents of a product network and finally collection of historical and statistical results. The extension of the proposed techniques so as to incorporate other functions of the production cycle of contracts is limited only by the extent of one's imagination. Customer interfaces such as drawing approval, staged payments and witnessed tests, subcontractors' activities, vendors' progress, commerical interfaces (e.g. insurance coverage, bank involvement, lawyers' consultancies, etc.) and shipment arrangements are the most common activities interfering within a manufacturing cycle. Moreover, the network diagram can be extrapolated at both ends to take into account pre-manufacturing and post-shipment activities. Marketing, estimating, engineering and production control can be incorporated in the plan so that their activities can be scheduled and their performance checked against plans. Erection and commissioning activities and materials can be displayed at the other end of the "networked" bill, thus accomplishing the full production cycle of any contract. The idea of such an extended BOM structure can be illustrated in conceptual form, as in Figure 4. It may be called a "Hyper Bill of Material" for a contract.

A forward and backward time analysis will produce the early and late planned dates for each activity in the Hyper Bill of Material. Resource allocation and scheduling, performed in conjunction with other existing contracts, will then produce the fixed scheduled dates for this particular contract. These scheduled dates of manufacturing activities will be fed into the MRP logic for the generation of the necessary purchase and work orders.

This approach differs from that taken by Aquilano and Smith [1,9] in integrating Critical Path Method and MRP for project work. Instead of using Network Analysis concepts as the driver of the CPM-MRP system, the conventional project network is transformed into a traditional BOM structure with its reduced flexibility. Activities that must have more than one parent (e.g. labor) must be duplicated as many times as required and each copy linked to a single parent. All but the simplest of project networks are likely to be greatly enlarged when transformed into this format. Furthermore, the logical links between children and their parents are limited to finish to start which is likewise restrictive for many projects. The result of these constraints is bound to make the monitoring and control the project more difficult.

The product structure of Aquilano and Smith does allow non-material elements and the scheduling algorithm ensures that an activity appearing more than once in the network is only scheduled a single time. An interesting feature of the algorithm is that resource constraints and availability can be considered during the schduling process, providing a schedule tailored to the current resource inventories (storable resources) and expected availabilities (non-storable resources). In a make-to-order environment, however, these features are generally not necessary. Storable resources for such products usually fall into two categories: those commonly available, small and standard components that are kept of hand at a minimum stock level and those that are customized or otherwise too expensive to maintain in stock, hence only ordered when needed. The proposed approach here suggests that in the first case no special consideration is required of the system and in the second the ordering of parts in controlled by the MRP logic but not the MRP timing. Procurement leadtimes are already identified in the network. As for non-storable resources, the labor and equipment can be adequately scheduled by the network analysis techniques of resource aggregation and leveling, which will determine the effect of resource availabilities on the schedule well before manufacture begins. With these capabilities, it is possible to answer "what if" questions to determine the optimum quantity of resources to obtain, if necessary, and have available on a given project.

APPLICATION OF THE INTEGRATED MRP/NETWORK ANALYSIS SYSTEM

A rough cut flowchart of an Integrated MRP/Network Analysis system is illustrated in Figure 5, and a computer program is being developed following these procedures. All parts that are currently used in our hypothetical company are entered in a PMR (Part Master Records) file. The system issues unique, meaningless numerical 7 digits part number with the last 2 digits as check digits whenever new part is created in a PMR file [10], and a user describes the part by entering part description, unit of measure, part code, lead time and cost. A parent-child relationship is entered in a BOM (Bill of Material) file following the way to be manufactured. The system allows only one PMR file and one manufacturing BOM file per end product. Accordingly, all parts that are manufactured or purchased are recorded in a PMR file and their parent-children relationships are in the BOM file.

To better explain the application of the Integrated MRP/Network Analysis system, the example created in a previous section is also used in this section. The user adds 10 new parts shown in Figure 2 into the PMR file first, then, their parent-children relationships are added in the BOM file. The system does not allow reverse order of entering data. As the system starts, the user identifies a desired end product to be manufactured. By the identified end product, the system recognizes its own family-tree structure shown in Figure 2B, and ten "active" part numbers are screened out from many part numbers currently stored in the PMR file. The system transfers information of those ten "active" parts from the PMR file to a TAP (Table of Activities & Parts) file and their parent-children relationships are also transferred from the BOM file to a RAP (Relationship of Activities & Parts) file. The user adds subsequently "non-material" types of activities shown in Figure 3 into the TAP file and modifies their relationships in the RAP file accordingly. In the RAP file, relationships between activities or between an activity and a part can be expressed like relationships in precedence networks, as shown in Figure 1. The TAP file and the RAP file contain now the contract contents to deliver the make-to-order product to the customer. The system allows one TAP file and one RAP file per contract. A forward and backward time analysis computes the early and late planned dates for each activity in the Time Analysis module by utilizing the TAP and the RAP files. The time analysis results along with the critical path as produced by the system are shown in Figure 6.

Utilizing the dynamic capabilities of Network Analysis system, the Integrated MRP/Network Analysis system conducts resource aggregation and resource leveling. The time constrained resource leveling produces the scheduled dates for each activity without violating the project completion date. Non-storable resources are aggregated using the early or late planned dates generated by the Time Analysis module, or using the scheduled dates generated by the Resource Leveling module. Sample histograms are shown in Figures 7A, 7B and 7C. The level of available resources is compared to the resource demand level and corrective management action may be requested to dissolve conflicts, if necessary. Based on the profiles in Figures 7A, 7B and 7C, the optimum schedule is shown in Figure 7C, as generated by the Resource Leveling module, even though this histogram shows resource over-utilization for a short period time. A management decision may be to increase the resource level for a short period of time (e.g. hiring more men, sub-contracting some work) to avoid any delay in the project completion date. Alternatively one could extend the project completion date after consulting with the customer. However, in many cases, contracts will not necessarily become overdue provided that delays have not exceeded the remaining float of activities (i.e. the difference between latest finish and scheduled finish). This feature makes an Integrated MRP/Network Analysis system superior to MRP in which any dalay is bound to cause inevitable expediting for the remaining tasks. With the scheduled dates, the MRP module computes the firmed date for each activity after interacting with inventory records and open/planned order records. Firm planned purchase and manufacturing orders with their respective dates are then issued for excecution. Finally, cost elements on activities are utilized by the Cost module to produce reports on cash expenditure versus time which is used for monitoring cash-in and -out flow on contracts, both individually and cumulatively. A typical cash flow curve for a given contract is shown in Figure 8.

The development of the computer program implementing the Integrated MRP/Network Analysis system was started in July 1986 and currently is in the process of developing the Resource Leveling module. After completion of the Resource Leveling module, an MRP module will be developed to raise firm planned purchase orders for all purchased items and manufacturing orders for all manufactured items.

CONCLUSIONS

Given that make-to-order manufacturing lies somewhere between job-shop manufacturing and project work, it seems logical that one could combine the appropriate features from the analytical tools available for these applications into a single system capable of handling the unique requirements in this environment. From Network Analysis systems one gains the flexible network structure, which can handle non-material items, allowing for the consideration of activities like testing, inspection and third party interfaces. Direct association of resource and cash requirements to each work item makes provision for subsequent resource scheduling and cash flow projections. Network Analysis also offers a large variety of relationships, which give extra flexibility in producing contract workflow models. As for the time analysis, network systems perform both forward and backward time runs, which reveal much desired floats for most production activities, as opposed to "stiff" schedules generated by MRP.

The major characteristics of the proposed Integrated MRP/Network Analysis system can be summarized as follows:

a. The conceptual similarities between a CPM and a manufacturing system (i.e. geometry and time analysis), provided the grounds for a combination aiming at managing all of the tasks, regardless of material content, encountered in a multi-contract, multi-resource environment.

b. The entire system is geared to contractual production with the scheduling module being the time and resource driver of all activities involved form customer's first request to on-site erection and commissioning, if applicable.

c. The scheduling module is functionally based on the CPM and encompasses also all of the non-manufacturing types of activities within and outside the manufacturing cycle of each contract. Manufacturing activities initially defined by customized BOM structures are also incorporated to the scheduling module by copying to it and appropriately enhancing contractual product structures so that the latter assume the form of precedence networks. The resulting network for each contract is a comprehensive definition of work, material, cost and resource requirements, providing the basis for production planning and scheduling.

The computer program implementing the Integrated MRP/Network Analysis system is in the process of developing the Resource Leveling module. The next and the final step will be development of our MRP module to simply raise firm planned purchase and manufacturing orders, with firm planned dates.

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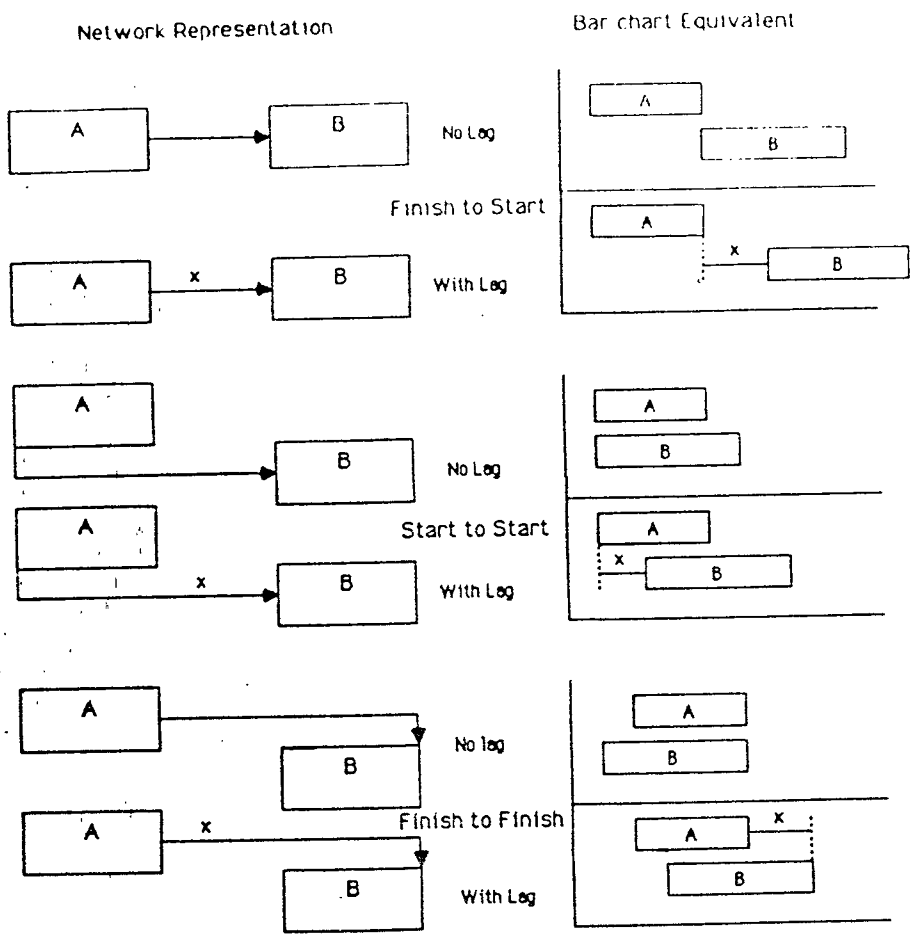


Figure 1. Activity relationships in precedence networks.

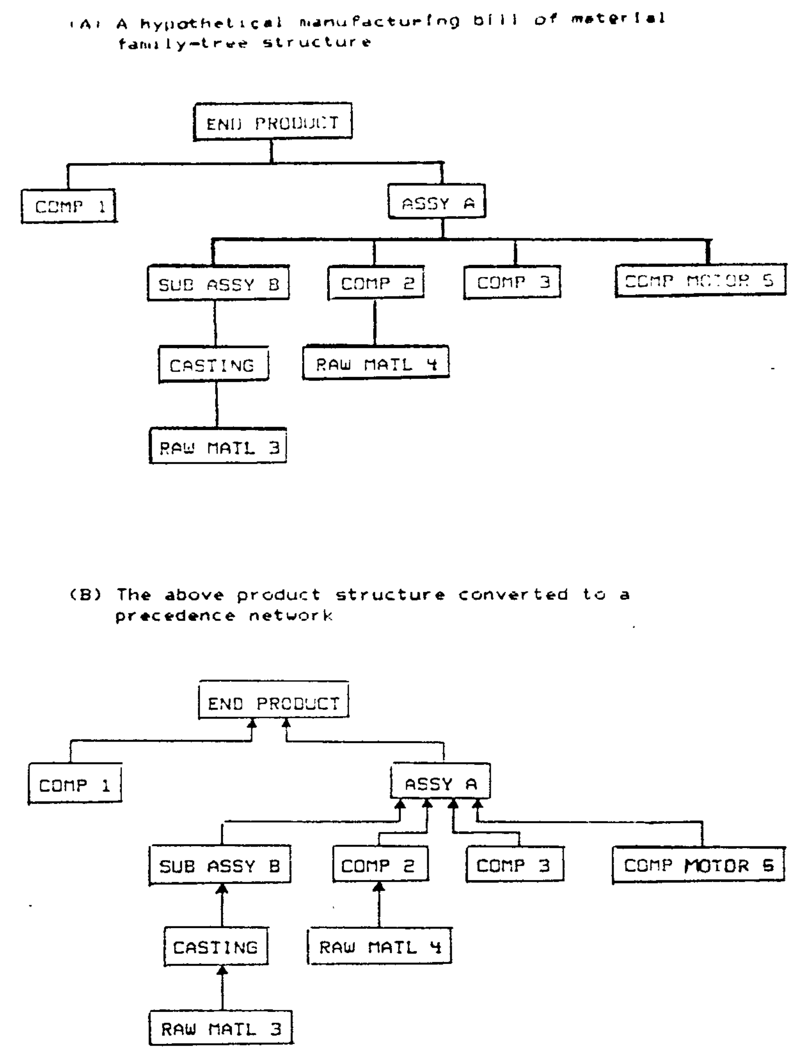


Figure 2. The principle of topological commonality between MRP and Network Analysis systems

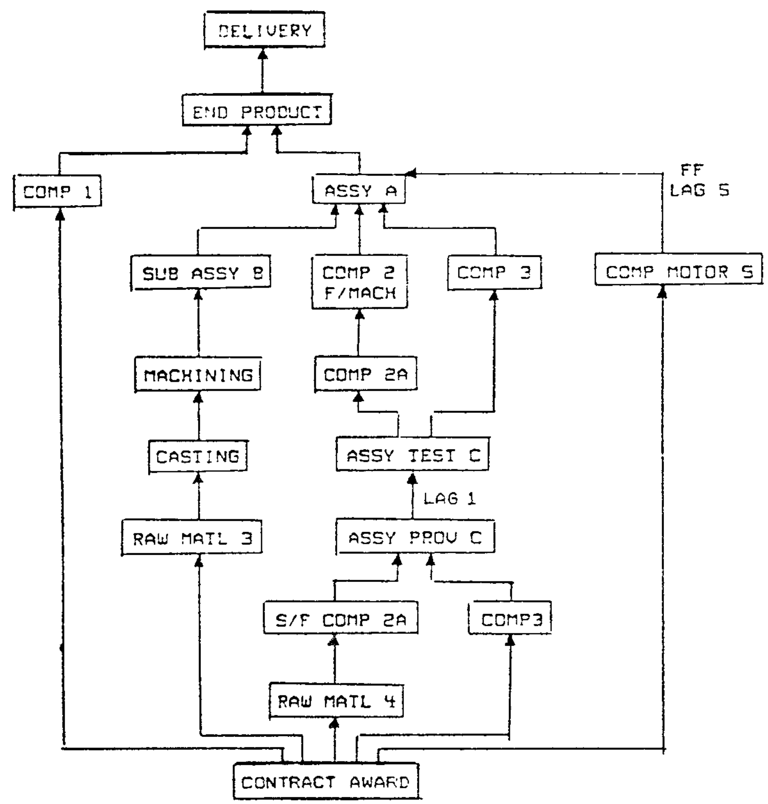


Figure 3. The precedence network drawing shown in Figure 2B enlarged to embrace various other types of manufacturing activities and relationships

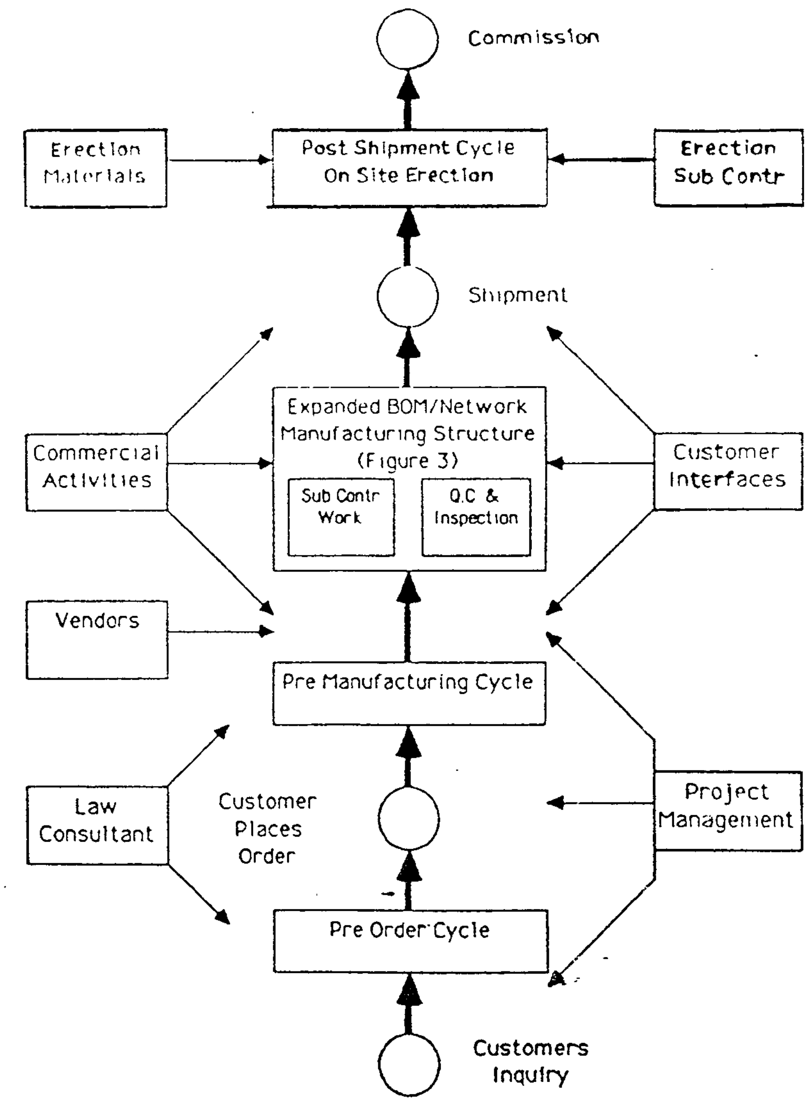
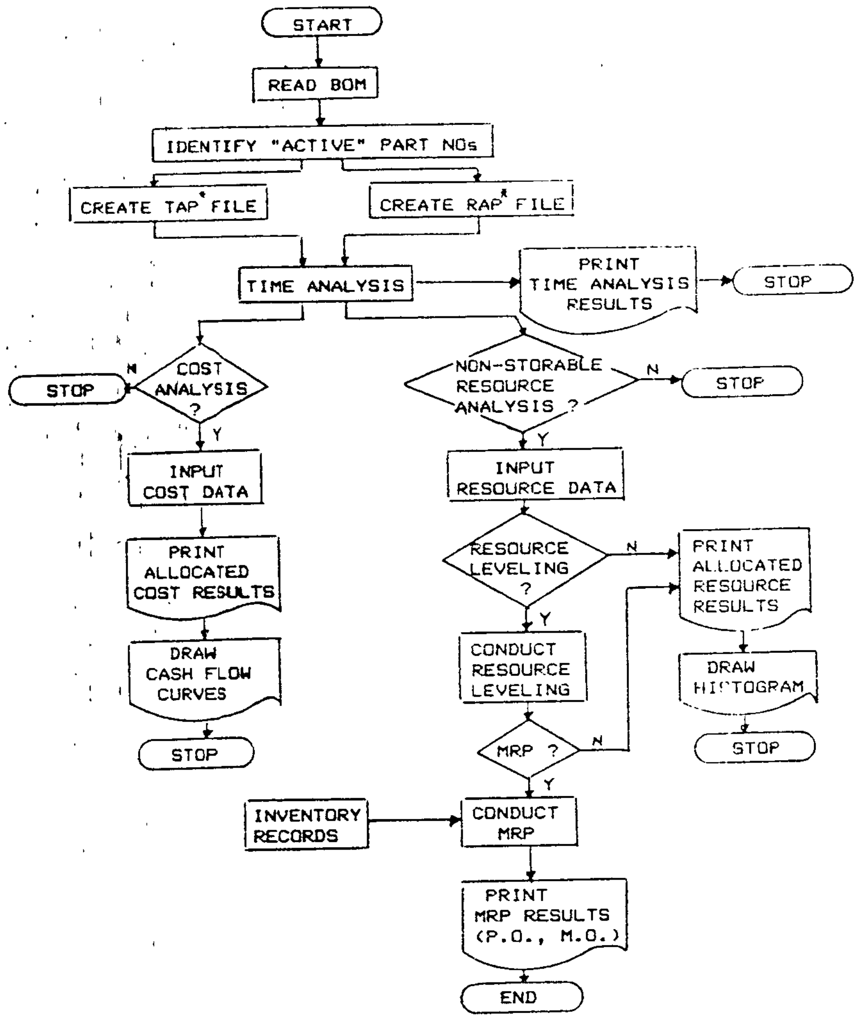


Figure 4. The "Hyper-Bill of Material" concept.



* TAP --- Table of Activity & Part numbers
* RAP --- Relationship of Activities & Parts

Figure 5. Flowchart of an Integrated MRP/Network Analysis system

R E S U L T S

Project has 1 Starting activity(ies)

The starting Time for Job 18 has 1 Time units (morning)

Total number of Activities and Parts in Project 18

Total number of Links in Project 2[illegible]

Duration of Project 21 Time units

P R O J E C T   S C H E D U L E

REF NO.	ACT # /PART #	TYPE	DURATION /LEAD TIME	PLANNED START E	PLANNED START L	PLANNED FINISH E	PLANNED FINISH L	FLOAT T	FLOAT F
1	1002534 END PRODUCT	M	2	17	17	18	18	0	0
2	1002639 COMP 1	B	3	2	14	4	16	12	12
3	1002744 ASSY A	M	3	14	14	16	16	0	0
4	1002849 SUB-ASSY B	M	1	7	13	7	13	6	6
5	1002954 CASTING	M	2	4	10	5	11	6	0
6	1003013 RAW MATL 3	B	2	2	8	3	9	6	0
7	1003118 COMP 2 F/MACH	M	2	12	12	13	13	0	0
8	1003223 RAW MATL 4	B	3	2	2	4	4	0	0
9	1003328 COMP 3	B	2	10	12	11	13	2	2
10	1003433 COMP MOTOR 5	B	2	2	10	3	11	8	0
11	999 DELIVERY	E	3	19	19	21	21	0	0
12	200 MACHINING	O	1	6	12	6	12	6	0
13	300 COMP 2A	O	2	10	10	11	11	0	0
14	490 ASSY TEST C	O	1	9	9	9	9	0	0
15	450 ASBY PROV C	O	1	7	7	7	7	0	0
16	350 S/F COMP 2A	O	2	5	5	6	6	0	0
17	1003328 COMP 3	O	2	2	5	3	6	3	3
18	101 CONTRACT AWARD	S	1	1	1	1	1	0	0

C R T I C A L   P A T H

REF NO.	18	-------	REF NO.	9
REF NO.	8	-------	REF NO.	16
REF NO.	16	-------	REF NO.	15
REF NO.	15	-------	REF NO.	14
REF NO.	14	-------	REF NO.	13
REF NO.	13	-------	REF NO.	7
REF NO.	7	-------	REF NO.	3
REF NO.	3	-------	REF NO.	1
REF NO.	1	-------	REF NO.	11

Figure 6. Time Analysis Results of network shown in Figure 3

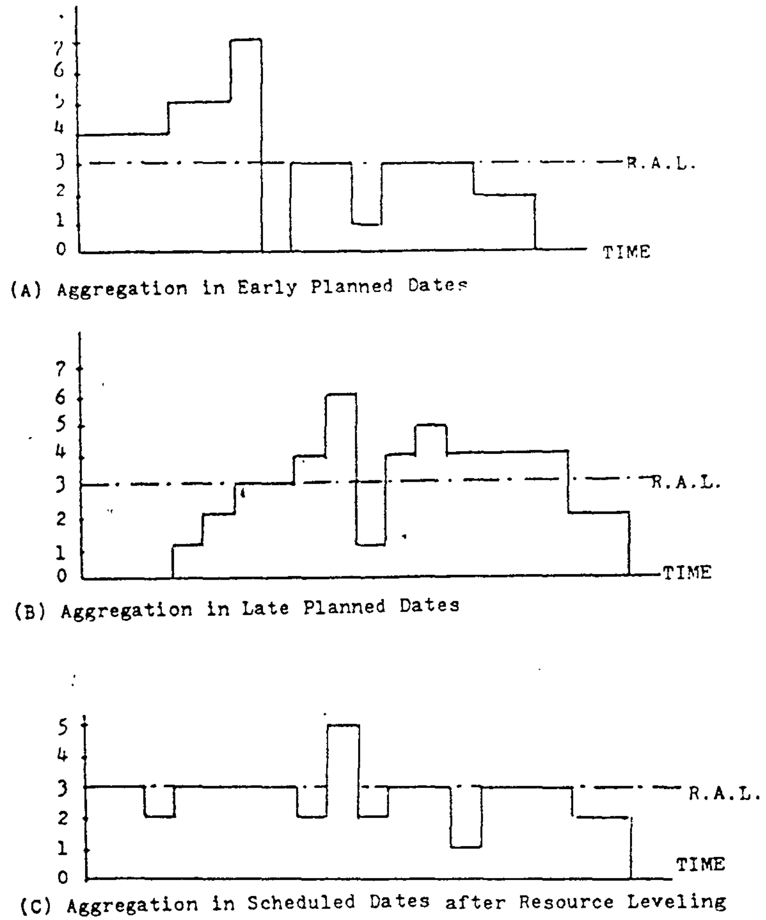


Figure 7. Aggregated Non-storable Resource Histogram

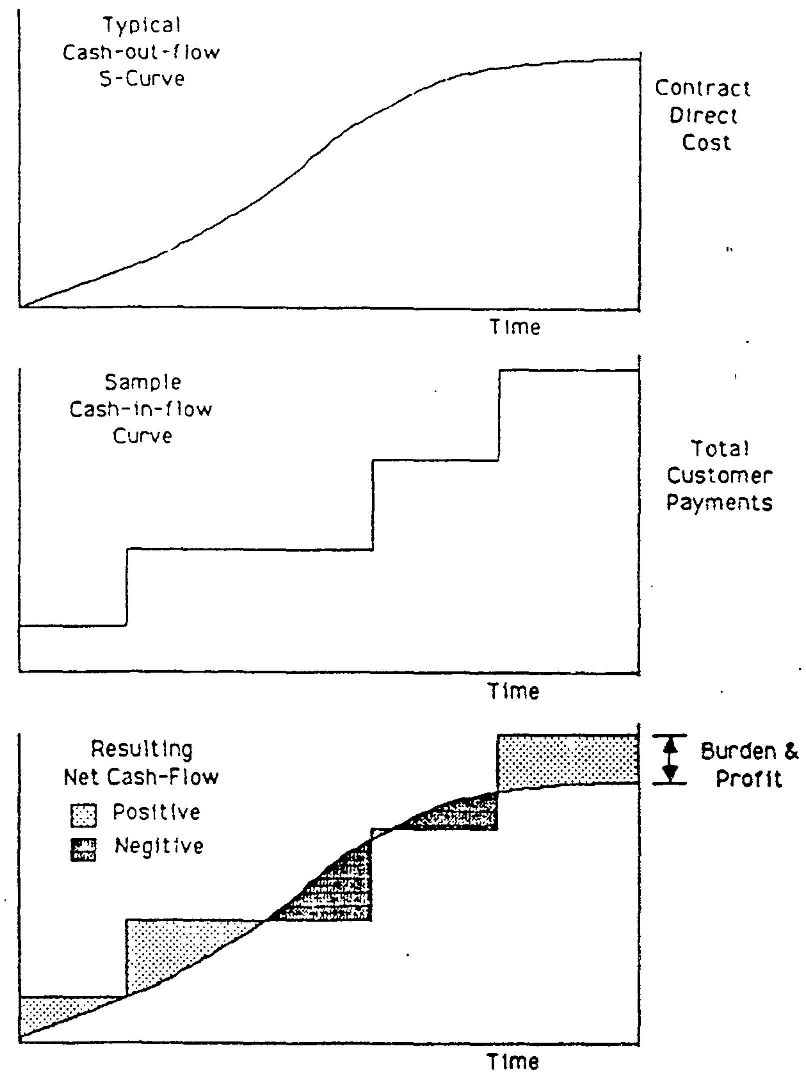


Figure 8. Typical Cash in and out flow curves.