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BILL OF RESOURCES AND PRIORITY-CAPACITY BALANCING

MGT2405, University of Toronto, Denny Hong-Mo Yeh

Load and capacity are terms that are often used interchangeably. The two terms, however, have very different meanings. Load is the amount of work to be done at a work center in a specified period. Capacity is the amount of work that can be processed at a work center within a given time period. Capacity describes the ability of a resource to produce items while load gives the amount of a resource's capacity that is required to complete a released or scheduled manufacturing order. The load on a work center is the sum of the required hours for all the planned and released orders to be run at the work center in a specified period.

In Figure 1, the tank is equivalent to a resource, the depth of water in the tank is the work-in-process (WIP) inventory level, the input rate of the water is the load, and the output rate of the water is the capacity. We use "rates" because both the load and capacity are amounts in a given time period. In order to keep the WIP inventory at a constant level, the capacity should equal the load. If the load exceeds the capacity, the planned and scheduled quantity exceeds the amount that the resource can produce, and the WIP inventory increases. When the load is below the capacity, WIP inventory level decreases or even goes to zero, leaving the resource idle. The output rate of the water tank, i.e. the capacity, can normally be adjusted so that the WIP inventory level can be kept stable even if the load fluctuates.

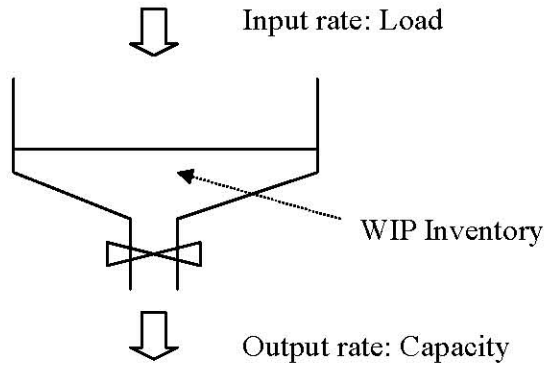


Figure 1: Load and Capacity

In material management, input rate is typically the demand rate for a resource or system, while the production rate is the output rate. *Cycle time* is the length of time that starts when a material enters the system and ends when it exits. *Throughput* is the total volume of production through a system per unit of time. Therefore, throughput equals WIP inventory divided by cycle time.

Fundamental Data for Load

We have discussed how to describe products with the item master file and bill of material file in Chapter Four. We now discuss the approach used to represent manufacturing processes. In an ERP or MRP II system, some files are commonly used to describe the production routes, machine capacities, resource requirements, and precedence of processes.

- *Work Center*

A work center is a specific area that can be considered as one unit for purpose of capacity planning and detailed scheduling. A work center can be a machine and/or people, a group of machines and/or people with identical capabilities, a group of joint operation machines and/or people, etc.

- *Routing*

Routing is the detailed description of the method for manufacturing a particular item. It includes the sequence of operations to be performed, the operation names, the various work centers involved, the machines to be used in each work center, the standard times for set-up and run in machines and/or work centers, the labor allocated, and the output quantity of a run. An operation is a job or task usually done essentially in one location. It consists of a job (material) and a location (machine, workstation, or work center). An operation number is a unique number that identifies an item being processed in a facility. Detailed information about the machines used in routing can be kept in a work center file that describes the machines, sequence of machines, standard setup and run times, and labor allocated to a work center. In some companies, routing also includes information on tooling, operator skill levels, inspection operations, and testing requirements, etc... Routing is sometimes referred to as the routing sheet, route sheet, operation sheet, instruction sheet, manufacturing data sheet, or bill of operations. Table 1 is an example of routing sheet.

The key fields of a routing file consist of route code and operation number. Operation number specifies the sequence of operations in a route. Routing contains the detailed information of the characteristics that a machine or work center processing an item.

Table 1: Routing Sheet for Route X

Op No	Operation Name	W/C No.	Mach No.	Setup time	Run time	Labor	O/P qty
10	Pre-process	M1	-	100	2.6	1	2
11	Dbl milling		MD-01	40	1.9	-	-
11a	Dbl milling		MD-02	40	1.9	-	-
12	Drilling		DM-11	40	0.7	-	-
13	Tapping		DM-09	20	0.35	-	-
20	Lathe	L2	-	40	2.2	1	1
21	Lathe		LN-05	40	2.2	-	-
21a	Lathe		LN-06	40	2.2	-	-
30	Post-proc	C1	-	50	1.6	1	1
31	Horning		HV-04	40	1.2	-	-
31a	Horning		HV-05	40	1.2	-	-
32	Cleaning		CN-01	10	0.3	-	-

An operation is a job done at a work center. If an operation can be further divided into

more than one operation, it is a *joint operation*. Operations 11, 12, 13 and 31, 32, 33 above are joint operations. A job enters the joint operation and passes through all of the machines in a specified sequence. The setup times and run times may not be equal at each machine. For planning and control, however, only work center level (joint operation) setup times and run times are considered. The setup time for a joint operation is the time during which the work center stops for changing molds, jigs, or fixtures to produce a job. The run time is the time between the completions of two discrete units of production from the work center.

If a worker is taking care of many semi-automatic machines (work centers), then each machine is allocated a fraction of worker. If many workers are operating a work center, then that number of workers is allocated to that work center.

Some work centers are engineered to produce more than one unit of product in each run; the output quantity per run is also recorded in the routing file.

Alternate routing is a less preferred routing that results in an identical item. The computer system must be able to accept alternate routings for specific jobs. In Table 1, operations 11a, 12a, and 13a are alternate routings.

- *Bill of Resources (BOR)*

A BOR is a listing of required capacities for key resources needed to manufacture one unit of a *selected item or family*. A BOR with resource requirements further defined by a lead-time offset is called *Product Load Profile*.

A bill of labor (BOL) is a bill of resource where the resource is labor. Routing is similar to item master; BOR and BOL are similar to BOM. The file structure of BOR is similar to that of a BOM. Making one product or family takes a certain number of hours in one work center. The product or family in BOR is equivalent to the parent in BOM, the work center is equivalent to the component, and the standard time required is equivalent to “quantity-per”. The BOR structure of the example in Table 1 is illustrated in Figure 2.

Since different items may have the same route, the parent field in a BOR record is normally defined as “*route code*”. Different items may have the same route code. The

route code for an item is specified in the item master. In the example of Figure 2, we assume that the route code has a default value – part number.

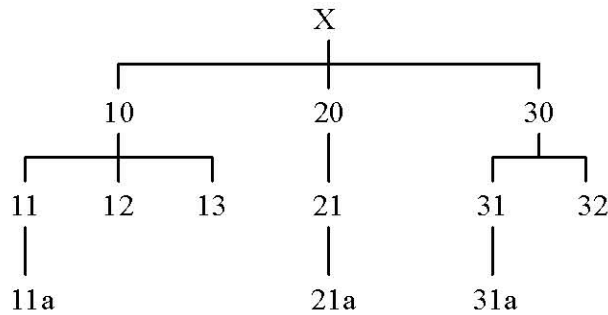


Figure 2: BOR Structure

Table 2: BOR File

Parent	Component	Ref. No	Qty-Per	Alternate
X	10		2.3	N
X	20		2.6	N
X	30		2.1	N
10	11	1		N
10	11a	1		Y
10	12			N
10	13			N
20	21	5		N
20	21a	5		Y
30	31			N
30	31a	7		Y
30	32	7		N

The “qty-per” in the BOR file is the standard total hours required by one unit of the item that is processed in a specific work center. The formula is

$$\text{Qty-per} = (\text{setup time} + \text{run time} * (\text{standard lot size} / \text{qty per run})) / \text{standard lot size}$$

If the standard lot size of X is 100, then the “qty-per” for route X and operation 10 is

$$\text{Qty-per} = (100 + 2.6 * (100 / 2)) / 100 = 2.3$$

- *Resource Profile*

Resource profile is the standard hours of load that a scheduled item places on a resource in a specific time period. The resource profile is often used to predict the impact of the scheduled item on the overall schedule and on the load of the key resources. BOR describes the loads of resources required by one unit of an item; resource profile describes the resources requirement loads needed by a scheduled quantity of an item in various periods. The loads generated by a scheduled item are distributed among related resources and time periods.

Priority-Capacity Balancing

Priority defines the relative importance of jobs, i.e., the sequence in which jobs should be worked on. Planned order receipts (PORC) and scheduled receipts (SR) in an MRP report are priority plans. The master production schedules are also priority plans. MRP is a priority plan for materials while MPS is for end products. Priority planning is the function of determining what, how many and when resources are needed. A priority plan determines the load of resources. It is realistic only when the capacity exceeds the load in each time period. Priority plans in an ERP or MRP II system include production plan (PP), master production schedule (MPS), and material requirement plan (MRP). Above the production plan, there is usually a business plan of long-range strategy. Production planning usually covers at least a year of operation and is also considered long-term planning. MPS and MRP are considered short-term plans, covering only several months.

- *Business Plan*

A statement of long-term strategy and revenue, cost, and profit objectives usually accompanied by budgets, a projected income statement, a projected balance sheet, and a projected cash flow statement. A business plan is usually stated in terms of dollars and grouped by product family. It provides direction and coordination among marketing, production, engineering, and financial planning. Marketing planning is responsible for determining the desired level of customer service, amount of sales, quantity of products supplied, pricing, promotions, and so on. Production planning must satisfy the goals set by marketing plans. It determines the production level and inventory level with the objective of using materials, equipment, and labor as efficiently as possible. Engineering planning is responsible for R&D, new product design, and existing product modifications. It works with marketing and production to

produce designs for products that will sell in the market, yet can be produced economically. Financial planning is responsible for deciding the sources and uses of funds available to the firm. It also generates projected financial statements such as income statement, balance sheet, and cash flow based on marketing, production, and engineering plans.

- *Production Plan*

Based on the business and marketing plans, production planning determines the quantities of each product family that must be produced in each period and the desired inventory levels. The level of detail of production planning is not as high as MPS or MRP. It plans the product family instead of each individual end product, as is done in MPS. In production planning, the planning horizon is six to eighteen months, the time bucket length is one month, and the production plan is reviewed monthly or quarterly. In MPS and MRP, the planning horizon usually covers three to six months with a time bucket length of one week, and reviews are conducted weekly or biweekly. Production planning is usually stated as a monthly rate for each product family. Various units of measurement can be used to express the production plan: units, tonnage, standard hours, number of workers, etc. The production plan is management's authorization for the master scheduler to convert the scheduled quantities in a production plan into more detailed scheduled quantities in MPS. Production planning is normally coordinated with the functions of marketing, manufacturing, engineering, and finance.

- *MPS and MRP*

Production plans are further broken down into more detailed formations, MPS. Master production schedules are fed into MRP system to obtain the material requirement plans. In PP, the period length is normally one month and it is normally one week in MPS and MRP. The planning horizon is longer in PP than in MPS and MRP.

Priority represents what items are needed, how many of them are needed, and when they are needed. The marketplace establishes the priorities. Capacity is the capability of a manufacturing system to satisfy the needs of the marketplace in a given period. It depends on the resources of the company, i.e., machinery, labor, and financial resources. In the short range, capacity is the amount of work machinery and labor can perform within a given period. Manufacturing must devise plans (MPS and MRP) to balance the demands of the

marketplace (priority) with its resources (capacity). Short-term priority-capacity can only be balanced by resource adjustments such as reallocation of labor, overtime, and subcontracting. In the long run, capacity can be balanced with market demand through long-range decisions such as the building of new plants and the purchase of new equipment. We now discuss various definitions of capacities.

- *Theoretical Capacity*

The maximum output of a manufacturing system in a given period, allowing no adjustment for preventive maintenance, unplanned downtime, shut down, etc.

- *Rated Capacity*

The expected output capability of a resource or system. It is equal to the product of hours available, efficiency, and utilization. Rated capacity is also called calculated capacity or nominal capacity.

- *Budgeted Capacity*

The total volume of mix of products in a given period through a manufacturing system on which the financial budgets are set and the overhead absorption rates are established.

- *Demonstrated Capacity*

Demonstrated capacity is proven capacity that is calculated from actual performance data and is usually expressed as the average output in standard hours. Demonstrated capacity is derived from multiplying the average number of items actually produced by the standard hours per item.

- *Productive Capacity*

The maximum of the output capabilities of a resource, or the market demand for that output for a given time period.

Priority and capacity are balanced by various techniques. For PP, MPS and MRP, the

corresponding capacity planning tools are resource requirement planning (RRP), rough-cut capacity planning (RCCP), and capacity requirement planning (CRP). Figure 3 shows the relations of the priority and capacity plans.

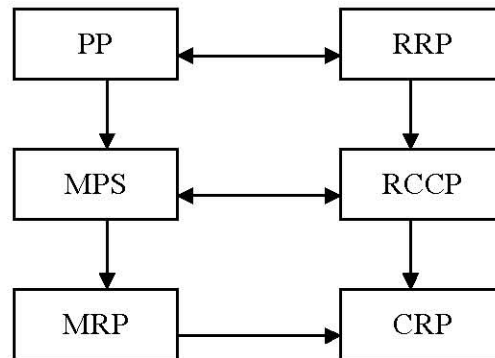


Figure 3: Relations of Priority and Capacity plans

- *Resource Requirement Planning*

Once the production plan is established, it must be compared to the existing resources of the company. This procedure is called resource requirement planning or resource planning. The bill of resource (BOR) of a product family shows the quantity of critical resources (machinery, labor) needed to make one average unit of the product family. For the product X in Table 2, if 500 units of X are planned in a given period in the production plan, the required capacities in hours for work center 10, 20, 30 are 1150, 1300, and 1050, respectively. The labor requirement is 3500 hours.

RRP addresses those resources that take long periods of time to acquire. RRP decisions always require top management approval.

- *Rough-Cut Capacity Planning*

Rough-cut capacity planning converts the MPS into requirements for critical resources in order to check whether sufficient resources are available to support the MPS. Critical resources include labor, machinery, and critical parts. Critical parts are checked by a critical part BOM to see if enough critical parts are available to complete the MPS. Critical capacities are checked to ensure that enough capacity is available to complete the MPS, using overall factors, bill of resource, and resource profile. The procedure of RCCP is similar to RRP. The difference is that RCCP considers products

while RRP considers product families.

Since the time bucket length of RCCP is shorter, it sometimes includes lead-time offset. Lead-time offset is never included in an RRP procedure. We will describe three RCCP procedures in the next section.

- *Capacity Requirement Planning*

Master production schedules are inputs to the RCCP, while the PORC and SR of MRP are inputs to CRP. CRP is the procedure that determines in detail the amount of labor and machinery resources required to accomplish the tasks of an operations plan. Through the use of standard times in routing and bill of resources, the SR and PORC are translated into hours of work, by work center and by time period. Lead time of each operation is considered in the CRP procedure. CRP differs from RCCP by that CRP processes all the machines or operations while RCCP processes only critical resources.

Case Study: RCCP

The BOM of product X and Y are shown in Figure 4.

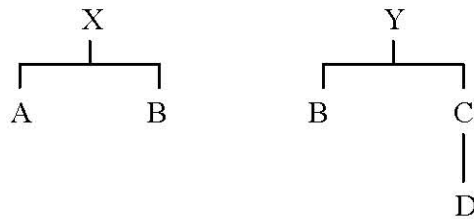


Figure 4: BOM

The BOM file is shown in Table 3.

Table 3: BOM File

Parent	Component	Qty-per
X	A	1
X	B	2
Y	B	1
Y	C	2
C	D	2

Table 4: Routing

Part Number	Operation #	Work Center	Setup Time	Run Time
X	10	100	1.0	0.025
Y	20	100	1.0	1.250
A	30	200	1.0	0.575
	40	300	1.0	0.175
B	50	200	2.0	0.067
C	60	200	2.0	0.080
D	70	200	2.0	0.0425

The standard lot sizes are specified in the item master file, which are used for calculating the unit time as shown in Table 5.

Table 5: Unit Time of the Operations

Part Number	Operation #	Work Center	Lot Size	Unit Time
X	10	100	40	0.05
Y	20	100	20	1.30
A	30	200	40	0.60
	40	300	40	0.20
B	50	200	60	0.10
C	60	200	100	0.10
D	70	200	100	0.0625

The MPS is shown in Table 6.

Table 6: MPS

Product	1	2	3	4	5	6	7	8
X	30	30	30	40	40	40	32	32
Y	20	20	20	15	15	15	25	25

- *Capacity Planning Using Overall Factors*

The first step is to calculate the capacity requirement of the MPS for overall key resources. From Table 3 and Table 5, we have the unit capacity requirements of the products in Table 7.

Table 7: Unit Capacity Required

Product	Time Required
X	1.05
Y	1.85

Then we calculate the overall capacity requirement of the MPS in each period, as shown in Table 8.

Table 8: Overall capacity Requirement

Period	1	2	3	4	5	6	7	8
Capacity	68.53	68.53	68.53	69.78	69.78	69.78	79.88	79.88

The percentages of the loads in key resources shown in Table 9 are determined by historical data.

Table 9: Key Resources Usage

Key Resource	Usage %
100	60
200	30
300	10

The overall capacity requirement is allocated to each key resource in each period by the historical ratio, as shown in Table 10.

Table 10: The Result of RCCP by using Overall factors

W/C	1	2	3	4	5	6	7	8
100	41.12	41.12	41.12	41.87	41.87	41.87	47.93	47.93
200	20.56	20.56	20.56	20.93	20.93	20.93	23.96	23.96
300	6.85	6.85	6.85	6.98	6.98	6.98	7.99	7.99
Total	68.53	68.53	68.53	69.78	69.78	69.78	79.88	79.88

- *Capacity Planning Using Bill Of Resources*

First, we determine the capacity requirements of each item for the key resources (BOR) from the routing file. Secondly, we determine the capacity requirements of end items for the key resources by using BOM to sum up the components' capacity requirement, as shown in Table 11.

Table 11: Bill Of Resources

Work Center	X	Y
100	0.05	1.30
200	0.80	0.55
300	0.20	0.00

Last, we calculate the capacity requirement of each MPS item for the key resources in each period. The result is shown in Table 12.

Table 12: The Result of RCCP by using BOR

W/C	1	2	3	4	5	6	7	8
100	27.50	27.50	27.50	21.50	21.50	21.50	34.10	34.10
200	35.03	35.03	35.03	40.28	40.28	40.28	39.38	39.38
300	6.00	6.00	6.00	8.00	8.00	8.00	6.40	6.40
Total	68.53	68.53	68.53	69.78	69.78	69.78	79.88	79.88

- *Capacity Planning Using Product Load Profile*

In the first step, we determine the product load profile for each MPS item with BOM, BOR, and lead items. A BOR with the resource requirements further defined by a lead-time offset is called *Product Load Profile*. The product load profile is shown in Table 13.

Table 13: Product Load Profile

Lead-time Offset	-2	-1	-0
X			
W/C 100	0.00	0.00	0.05
W/C 200	0.60	0.20	0.00
W/C 300	0.00	0.20	0.00
Y			
W/C 100	0.00	0.00	1.30
W/C 200	0.25	0.30	0.00

We then use product load profile and MPS to calculate the resource profile for each MPS entry. By summarizing the resource profiles, we obtain the capacity requirements of the key resources in each period, as shown in Table 14.

Table 14: The Result of RCCP by using Product Load Profile

W/C	Past due	1	2	3	4	5	6	7	8
100	0.00	27.50	27.50	27.50	21.50	21.50	21.50	34.10	34.10
200	58.03	35.03	39.78	40.28	40.28	37.98	39.38	39.38	42.43
300	6.00	6.00	6.00	8.00	8.00	8.00	6.40	6.40	6.40
Total	64.03	68.53	73.28	75.78	69.78	67.48	67.28	79.88	82.93

Case Study: International Airport Services Revisited

Before revisiting the International Airport Services (IAS) case, we first take a deeper look into the product load profile approach described in the previous RCCP case. In fact, the load profile approach can be implemented by the standard MRP procedure. First, all the operations are defined in the item master file as items with lead-times set as 0. Second, a standard BOM for the operations, as shown in Table 15, is established by using BOM in Table 3 and unit time in Table 5. In the operations BOM, the qty-per equals the summarized qty-per in BOM (e.g. qty-per of D in Y is 4) times the unit time. The product load profile in Table 13 can easily be obtained from the operations BOM. After MRP calculation, the result of RCCP as shown in Table 14 can be obtained by sorting the MRP result by work centers.

Table 15: Operations BOM for RCCP Case

Parent	Component	Work Center	Qty-per	Offset-time
X	10	100	0.05	0
Y	20	100	1.30	0
10	40	300	0.20	1
40	30	200	0.60	1
10	50	200	0.20	1
20	50	200	0.10	1
20	60	200	0.20	1
60	70	200	0.25	1

We now revisit the IAS case described in Chapter Two. In the RCCP case, we assume each operation takes one period to complete, so the parent-child combination appears only once in the operations BOM, and all the off set times except X and Y are set equal to 1. However, the operations of toilet cleaning and catering load in the IAS case take 2 periods to complete. The operations BOM records are listed in Table 16, which is a repeat of Table 11 in Chapter Two. To distinguish operations from the resources they use, we add a work center column in Table 16. Since no operation uses the same resources, the work centers just take the operations' codes.

Table 16: Operations BOM for International Airport Services

Parent	Component	Work Center	Qty-per	Offset-time
X	A	A	1	0
Y	A	A	1	1
A	B	B	2	1
A	B	B	2	2
A	C	C	1	1
A	D	D	3	1
A	D	D	3	2
A	E	E	1	1

The “product load profile” for IAS case can easily be obtained from Table 16, as shown in Table 17. Using Operations BOM and standard MRP procedure or product load profile and RCCP procedure, one can obtain the same result as shown in Table 13 of Chapter Two.

Table 17: Product Load Profile for IAS Case

Lead-time Offset	-3	-2	-1	-0
X				
A	0	0	0	1
Y				
A	0	0	1	0
B	2	2	0	0
C	0	1	0	0
D	3	3	0	0
E	0	1	0	0

Case Study: Alternate Operations Planning Logic

In the previous section, we set all the operation’s lead-time as 0 and use offset time to schedule the operation. If the time required by an operation is more than 1 period, as in IAS case, we use multiple parent-component BOM record with different offset time to schedule several consecutive periods for that operation. In addition to this logic, which is a standard MRP logic, we can also use the standard MRP logic to schedule the operations in a different way. In this logic and the logic we are about to describe, we assume there is a standard lot size for each manufacturing batch, and the lead-time for a batch on a machine can be determined beforehand. The determination of lead-time considers standard lot size, setup time, run time, material handling time, waiting time, etc. Since the standard MRP logic does not consider the capacity limit, more than one batch can be scheduled on a machine at the same time and causes resource overload, other procedures, sometimes called advanced planning and scheduling (APS), are required to solve the resource conflict problems.

We now use the standard MRP logic to schedule both the start time and the end time of an operation. The parent number X and Y in Table 15 and 16 are actually routing codes defined in the item master of part X and Y. Remember the default routing code of a part is its part number. In the RCCP case, we need to have a record in the item master file for each operation, as shown in Table 18. The ERP systems include a routing file, which is actually the item master file for the operations.

Table 18: Routing File (Item Master for Operations)

Operation Number	Operation Name	Lead Time	Work Center
X	X routing	0	n/a

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Y	Y routing	0	n/a
10	10	1	100
20	20	1	100
30	30	1	200
40	40	1	300
50	50	1	200
60	60	1	200
70	70	1	200

The operations BOM or bill of operations is shown in Table 19.

Table 19: Bill of Operations

Parent	Component	Qty-per	Offset-time
X	10	0.05	0
Y	20	1.30	0
10	40	0.20	0
40	30	0.60	0
10	50	0.20	0
20	50	0.10	0
20	60	0.20	0
60	70	0.25	0

Using the operations item master in Table 18 and operations BOM in Table 19, a standard MRP can obtain the same result as in Table 14. The start time of an operation is its POR period, and the end time is its PORC period minus 1. Notice that the work center column in Table 15 should be defined in the item master file instead of BOM file.

As for the IAS case, the item master for operations is list in Table 20.

Table 20: Operations Item Master for IAS Case

Operation Number	Operation Name	Lead Time	Work Center
X	Arrival	0	n/a
Y	Departure	0	n/a
A	Marshaling	1	A
B	Toilet cleaning	2	B
C	Refueling	1	C
D	Catering load	2	D
E	Garbage dumping	1	E

The bills of operations for the IAS case are shown in Table 21.

Table 21: Operations BOM for IAS Case

Parent	Component	Qty-per	Offset-time
X	A	1	0
Y	A	1	0
A	B	2	0
A	B	2	0
A	C	1	0
A	D	3	0
A	D	3	0
A	E	1	0

Using the operations item master in Table 20 and bill of operations in Table 21, a standard MRP can obtain the same result as in Table 13 in Chapter Two. The start time of an operation is its POR period, and the end time is its PORC period minus 1. Notice that the work center column in Table 16 should be defined in the operations item master file.