DRUM-BUFFER-ROPE SHOP FLOOR CONTROL

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The drum-buffer-rope (DBR) methodology now being implemented in a growing number of manufacturing organizations enables better scheduling and decision making on the shop floor.* It is based on the theory of constraints (TOC) [1, 2], a global managerial methodology that helps the manager to concentrate on the most critical issues. TOC focuses on the system's constraints, their exploitation according to the goal of the organization, and the implications of exploiting these constraints on the rest of the system.

The concepts of optimized production technology, DBR, and TOC were developed in [2, 3, and 4]. Goldratt [2] delineates the connection of the OPT principles to the steps of TOC, and a system overview of DBR, TOC, and OPT is proposed in [6].

The focus of OPT was the identification of bottlenecks in the manufacturing process, with the objective of basing the scheduling efforts on these bottlenecks. The essence of OPT philosophy was expressed by nine rules [4], which have been replaced by five more general and accurate steps constituting TOC. The term "bottleneck" is replaced by a broader term: constraint, defined as anything that limits a system from achieving higher performance relative to its goal.

The five steps:

- Step 1. **Identify** the system constraint(s).
- Step 2. Decide how to **exploit** the constraint(s).
- Step 3. **Subordinate** everything else to the above decision.
- Step 4. **Elevate** the system constraint(s).
- Step 5. If, in the previous steps, a constraint has been broken, go back to Step 1, but do not let "inertia" become the system constraint.

Drum-Buffer-Rope—A Scheduling Technique

A "drum" is the exploitation of the constraint of the system; the constraint dictates the overall pace of the system. The constraint may be a resource, market demand, scarce raw material, or management policy. In many cases, a drum has to include a detailed schedule of the constraint in order to ensure the exploitation of the constraint.

A "buffer" is protection time. Buffers are used to protect something from adjacent disruptions. The protection is expressed in time units, since the parts are planned to reach the protected area some time before they are scheduled to be processed. Disruptions might stem from a variety of reasons: breakdowns, absenteeism, fluctuations in setup times, unreliable vendors, scrap, or just unavailability of a certain resource because it is being used in other jobs. Buffers are planned only in critical areas that need to be protected; it is obvious that the drum (i.e., the schedule of a capacity constraint resource) should be protected from disruptions on adjacent operations.

A "rope" is a mechanism to force all the parts of the system to work up to the pace dictated by the drum and no more. This is done, in DBR implementations, by creating a detailed schedule for releasing raw material into the shop floor.

Scheduling in DBR

There are three basic steps:

- Step (a) Schedule your constraint(s) (in order to do this you will have to determine the master production schedule at the same time). The MPS is subjected to the capabilities of the system constraints only. Next exploit the constraints according to the organizational goal. (A bottleneck that works all the time is not necessarily exploited. It should work on products that are the most profitable and only on those which are going to be sold soon.)
- Step (b) Determine the buffer sizes.
- Step (c) Derive the materials release schedule according to steps (a) and (b).

These three basic steps are repeated every time the planning process is executed. Two more general actions are assumed to be taken whenever necessary:

* EDITOR'S NOTE: I have personally verified two successful implementations in plants in Texas, one of which quadrupled company earnings.

- Identify the system constraints.
- Determine a general subordination policy, which concerns the way the nonconstraints should be activated. This step may or may not include a detailed or partial schedule for the nonconstraint work centers.

Exploitation

Step 2 is exactly the definition of a drum—if the constraint lies in the market, then a detailed shipping schedule is to be derived in order to satisfy the whole market. In this case scheduling the shipping is the essence of the constraint's exploitation, and the detailed shipping schedule is the drum.

Step (a) of DBR implies constructing the MPS and the detailed shipping schedule according to the constraint capabilities and maximizing the contribution to the bottom line of the constraint's available time [1, 4]. Scheduling the constraint [Step a] is a further implication of the constraint's exploitation. In the case of an internal constraint, a detailed schedule is needed because improvisations are risky to the exploitation, and also because the subordination areas have to be aware, in advance, of the drum needs.

Subordination

The purpose of Step 3 is to keep the exploitation intact. In a stochastic environment, there is the risk that the drum will be exposed to disruptions that occur elsewhere. The immediate action that can be taken is to plan buffers in front of the drum and the shipping dock. The buffer sizes reflect the amount of the fluctuations and the capacity level at nonconstraint resources. The capacity level is crucial because it determines the time needed for a nonconstraint resource to catch up after a disruption.

Ropes, another mechanism derived from Step 3, ensure that the nonconstraint will be subordinate to the drum by forcing the system to contain only material that is scheduled by a drum in the next buffer time frame. A nonconstraint resource that is engaged in processing parts that are not scheduled by a drum behaves in contradiction to the subordination rule, because it does not take advantage of its excess capacity to protect the drum.

The Environment Simulated

The simulation handles a plant with stable market demand. The horizon is two weeks.

The Plant Resources

The plant uses six different machines. The physical layout is shown in Figure 1 and the routing layout is given in Figure 2.

Product I is made from raw materials A, B, and D. Machine N processes rmA (raw material A) 13 min on average (TPP), and delivers the part to the W machine for 11 min, etc. Resource R is an assembly machine, each assembly operation being a simple 1:1 assembly. The upper row specifies the total weekly demand for product I (60 per week) and J (40 per week). There are 20 pieces of WIP past E2 operation (ready to be processed by M at E3). Another 10 lie past the G2 operation, and another 10 past the G3 operation.

A table of the work load on the resources, along with more simulation details, can be obtained upon written request to either author.

APPLYING THE DBR TECHNIQUE

M is clearly a capacity constraint of the system. The market demand for the most profitable product is a constraint as well. For a discussion of profitability see [1, 4].

Step (a): Schedule/Exploit the Constraint

Exploitation decisions and the MPS must be determined. The current weekly demand reflects the maximum capacity of M. A possible MPS for two weeks would be 120 I products and 80 J products. Shipping will be done in four equally spread shipments. The total work load (not including downtime) required from M during the two weeks, including 12 setups, is 4760 min out of the 4800 min available. The market demand is to be exploited by supplying everything on due date.

In scheduling the constraint, it is clear that E3 should be the first operation, since it already has the parts for

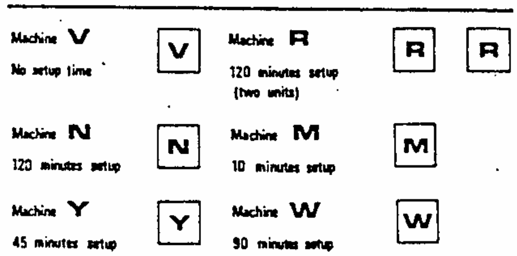

FIGURE 1: Resource layout. Apart from the average setup times, there is downtime associated with each resource. The downtime is 10% on average except on the M machine, which has only 1% downtime. Downtime is proportional to the time the resource is busy in production or setup.

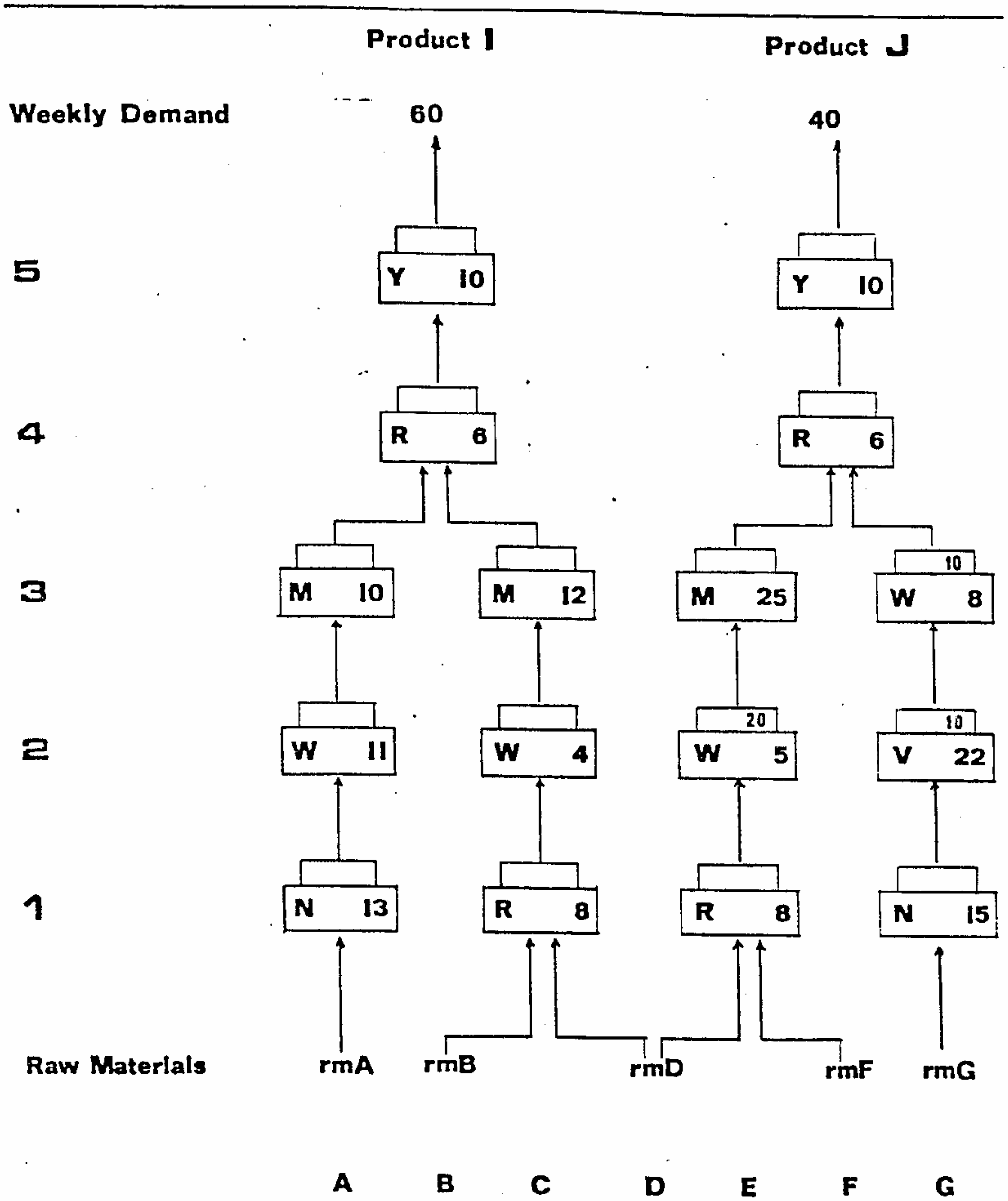

FIGURE 2: Layout of the routings for two products I and J. Flow is bottom up. Each box is an operation, done by a resource denoted by its capital letter. Numbers denote average time per part (TPP). Each operation is recognizable by its column/row, i.e., the leftmost W operation, being in column A and row 2, is A2.

the first batch. Developing the rest is straightforward. The M schedule is given in Table 1. The last line (for E3) is the demand for the third week. It is included because the rope needs to be set at the second week for week 3 demand.

Step (b) of DBR: Determine the Buffer Sizes

Only three types of buffers are needed:

- **Constraint buffer:** protecting M's operations. Size chosen: 9 hr. The initial size of the constraint buffer was chosen intuitively on the basis of several initial simulated runs made to give some sort of "gut feeling." The initial decision has to take into consideration that the buffer size should be equal to a fairly long, yet still realistic, lead time to the constraint. In a stable environment, operating under DBR methodology, where WIP is being limited by the rope schedule, the buffer size may be three times the average lead time to the constraint. The "three times" is based on experience and depends on realistic lead-time distribution.
- **Shipping buffer:** protecting the due dates. Size chosen: 6 hr. This buffer protects the due dates from disruptions on the way from the constraint buffer to the shipping dock.
- **Assembly buffer:** Size chosen: 9 hr. This type of buffer is needed in certain environments. Here it is created for the F4 assembly operation only. Assembly operation F4 has two feeding legs: one carries a part that was processed by the constraint and the other carries a "nonconstraint part." The leg with the nonconstraint part needs buffering (protection), otherwise the costly constraint parts will have to wait for the nonconstraints to reach the assembly.

TABLE 1: The M (Drum) Schedule

Operation	Quantity	Projected Start Hr
E3	20	0
C3	30	8
A3	30	14
E3	20	19
C3	30	28
A3	30	34
E3	20	39
C3	30	48
A3	30	54
E3	20	59
C3	30	68
A3	30	74
E3	20	79

TABLE 2: Rope Purchasing Schedule

Raw Material	Quantity	Hr
B	30	0
D	30	0
A	30	5
D	20	10
F	20	10
G	20	10
D	30	19
B	30	19
A	30	25
F	20	30
D	20	30
G	20	30
D	30	39
B	30	39
A	30	45
F	20	50
D	20	50
G	20	50
D	30	59
B	30	59
A	30	65
F	20	70
D	20	70
G	20	70

Step (c): The Rope Schedule

The calculation is apparently simple: The M's schedule minus the buffer size. The rope for the G raw-material parts are triggered by the assembly buffer. The derived schedule for that buffer is the same as the schedule for the E3 constraint operation. The rope purchase schedule is given in Table 2.

As C3 has to start at about hour 8, the release should be done at hour −1. This means that for the first C3 operation, the actual buffer is only 8 hr. This concludes the scheduling stage according to DBR.

Subordination Policy for the Nonconstraint Resources

The W resource is quite loaded, in spite of the fact that it is not a constraint. For this simulation run, a schedule for W was derived based on the constraint and the extra operation on G3. A control technique titled "buffer management" is usually used to monitor the execution of the schedule and for spotting problems which led to the decision to treat W differently from the other nonconstraints (see [7]).

In order to keep full flexibility in subordinating the other resources, the following working policy was incorporated into the simulator:

- If you don't have anything to do, do nothing!
- If work appears somewhere and you are not busy, set up to the new job.
- If you have more than one job to choose from, choose the one with the biggest work load. This rule, which is opposite to the shortest processing time decision rule, was chosen because it appears natural to a foreman. The fact that the resource has excess capacity enables us to let the foreman take decisions in a simple manner. If and when this leads to a wrong decision which might affect the system, buffer management technique is supposed to reveal it on time to make corrections.
- Once you start an operation, switch to another job only if you are idle at the moment.

Scheduling the capacity constraint did not include the lead time from the constraint to the shipping dock. The only concern is the last shipment. The shipping buffer was chosen to be 6 hr and thus it was estimated that the average lead time, from the capacity constraint to the shipping dock, will be less than that. The last M operation takes about 5 hr, so we can expect that about half of the last shipment will arrive when no overtime is added (the average lead time is estimated to be 2 to 2.5 hr).

The Simulation Runs

Sixteen discrete runs were performed under the above rules. On average 11.5 I units, out of 30, were missing in the last shipment. All in all the expectations were met; it was expected that the last shipment of product I would not be finished. Overtime of 1 to 4 hr (in the R and Y work centers and sometimes also M), was needed in order to finish everything. The results confirm the expectations of having, on average, more than half of the shipment ready, even without overtime.

ANALYSIS

The basic approach of DBR is of exploiting the system constraints and subordinating the rest of the system to the exploitation of the constraints. This is the essence of Steps 2 and 3 of TOC.

How Good Is the DBR Solution?

Any optimal solution regarding system performance has to conform to Steps 2 and 3. This is logically derived from the definition of a constraint (anything that limits the system's performance). Any optimal schedule has to exploit the constraint and to protect the exploitation—subordinating to it. A DBR schedule can be improved by

- Improving the exploitation.
- Improving the subordination.

Can the Exploitation be Improved?

There are trade-offs which depend on the market behavior and how the goal definition treats short-term profits relative to long-term profits (assuming profit is the system's objective function). One trade-off concerns the number of shipments per week. If we ship only once in two weeks, the plant will be able to produce more. On the other hand, a lead time of two weeks might cause a loss of market in the future. This trade-off decision is a key factor in the exploitation stage, Step (a).

Can Subordination be Improved?

There is a need to find the balance in the buffer sizes to see that they are the smallest that protect the constraint schedule (the drum). The way the nonconstraints are actually activated might influence the necessary minimum size of the buffers. Buffer management is a control technique, which provides a better way to handle the nonconstraints [7].

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Note: The two working papers [5] and [7], as well as the simulation details, may be obtained upon request from either author (addresses on title page).