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Drum-Buffer-Rope (DBR) a Competitive Strategy to Solve Problems of a Small and Medium Enterprise (SME) – A Case Study

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Abstract

Small and Medium Enterprises (SMEs) always face internal and external challenges. In the product market, there is an intense competition among SMEs and the bargaining power of the Original Equipment Manufacturer (OEM) is very high. SMEs have limited ability to sustain an unused capacity (over capacity), limited capability to invest, lack of systematic decision making, lack of planning and management deficiency. In order to get competitive advantage, they have to reengineer and redesign themselves. With the advent of technology in manufacturing, the quality and prices of the products are more of hygiene factors for an OEM and only one differentiator from its viewpoint is the due date performance of the SMEs. The objective of this paper is to improve sales and profit of a SME through better due date performance by synchronizing operations and material flows and making better decision on the shop floor. This paper also

shows how Drum-Buffer-Rope (DBR) approach of theory of constraints (TOC) acts as a competitive strategy to the SME in solving its varied problems in order to compete and lead in the product market. We conclude the paper by acknowledging a few shortcomings of the paper and discussing some future plans.

1.0 Introduction

Theory of constraint (TOC) over period has evolved as a management philosophy of continuous improvement (Kim et al., 2008). The TOC has grown in almost all areas of businesses (Victoria and Steven, 2003) and it has been widely accepted by practitioners and academicians who address both the accomplishments and deficiencies of TOC (Watson et al., 2007). There are various tools and techniques of TOC. Drum-Buffer-Rope (DBR) is one of the decision taking technique of TOC focusing on production scheduling (Schragenheim and Ronen, 1990) that controls the manufacturing lead time (Timothy et al., 1991). Its usefulness can be compared with other improvement tools like Kanban system (Gardiner et al., 1993) and traditional resource planning (Steele et al., 2005). Moreover, the DBR tool can effectively be implemented and executed in any firm irrespective of its size (small, medium or large firms).

SMEs constantly face challenges in business environment. They have limited ability to sustain an unused capacity (over capacity), limited capability to invest, lack of systematic decision making, lack of planning and management deficiency (Gupta et al., 2010; Thakkar et al., 2012). There are also some issues related to lack of quality consciousness (Ahire, 1996; Selvam, 1996), lack of trained workers (Dalu and Deshmukh, 2001), demand forecast mismatch and lack of synchronization of material flow with production priorities (Thakkar et al., 2012). However, the major issue turning out recently in the changing and uncertain environment is the timely deliveries of the products to OEMs. It becomes imperative for the SME to configure and manage their operations in order to compete in the product market.

Various latest management philosophies have been associated with SME. Achanga et al. (2006) analyse the critical success factors for lean implementation. Godecke and Peter (2004) study the Six Sigma in SMEs. Wu et al. (1994) compare the effectiveness of DBR in a furniture manufacturing environment. Olson (1998) addresses a TOC application in a service industry to improve its performance by exploiting the system's constraint via reducing the batch size. Draman and Salhus (1998) employ TOC based production planning and scheduling concepts in a production process of a paint plant. Gupta et al. (2010) stated that TOC helps SMEs to improve profitability by making significant better decisions in strategic areas. However, not much of the TOC principles have been applied in SMEs. And, DBR technique in particular needs to be explored in SMEs as to the best our knowledge, none of the paper explains a step by step planning and execution parts of the DBR in SMEs. In this paper, an attempt has been made to employ DBR in a SME explaining a step by step planning and execution parts of the DBR. The DBR approach helps to solve various problems of the SME to compete and lead in the product market. This paper also shows how the DBR becomes a competitive strategy to the SME to increases its sales and profit through better due date performance

2.0. The company background and it's manufacturing process

ABC Pvt. Ltd. is a Small and Medium Enterprise (SME) company situated in Solapur, Maharashtra district of India. In the initial years, the company started its operations as a machine-shop manufacturing automotive components, however later it has expanded into in-house development, manufacturing, and assembly of different varieties of lubricating oil pumps and the systems that are used in diesel engines. The ABC product portfolio includes Lube oil and Water pumps, Shell and Tube type oil coolers, Centrifuge filters, Assemblies and Sub-assemblies and fully finished components. These products are supplied to a wide customer base of large diesel engine manufacturers in India and exported to some customers located in the USA. These customers are basically OEMs. From the technological perspective the company has most advanced manufacturing system with state of the art machine shop for the quality production. They also have a design and development centre with all the advanced precision tools.

The company specializes in the custom design and manufacturing of the products. The OEM provides the detailed design parameters, drawings and standards of the required products and these products are then developed and manufactured in-house. For all the products, the casting components are purchased either in raw or semi-finished state which are then undergo the machining process in the machine shop. The machine shop is equipped with both the general and special purpose Computer Numerical Control (CNC) and Vertical Machining Centre (VMC) machines wherein a number of major machining operations like turning, drilling, fitting, assembly are carried out. Other operations that are performed in the machine shop include cleaning, inspection, packaging etc. Assembly shop is the last centre in the manufacturing process where sub-assemblies and directly outsourced components or subassemblies are assembled. The raw materials flow through different machines as per the sequence in which the final products are made. Most of the machines are common or shared to all the products and work in process (WIP) for a product is moved through the system in a batch as per its customer demand. The company also outsources many components and sub-assemblies from the third party suppliers that are often directly used at some sub-assembly and assembly operations. There are many store points on the shop floor where WIP inventories are stored and there is a dispatch section where the final products are stored and dispatched to the customers.

3.0 Problems in the manufacturing environment (Why DBR ?)

The company supplies the final products to all big Original Equipment Manufacturers (OEMs) in India. However, the market scenario for the company is a highly complex and competitive one. The company’s concentration in this industry is very low and various players are there, who can supply the similar product to the OEMs. Due to this, competition in this sector is very high, which gives rise to a situation where the bargaining power of the OEMs is very high and the margins realized by the SMEs are usually very low.

With the advent of technology in manufacturing, virtually every SME can deploy CNCs and VMCs thus the quality of the final products and their prices are more of hygiene factors and not a differentiator for the OEMs in the product market. In other words, good quality and low price products are expected by OEMs, hence these do not act as differentiating factors. Number of modern business practices have been implemented by the OEMs, hence timely delivery by SMEs is almost indispensable. In a B2B transaction, the due date performance thus plays a key role in differentiating one SME from the other.

Another problem typically with SMEs is their limited ability to sustain an unused capacity (over capacity), due to their small sizes and limited investment capabilities. This is also true for the company ABC for which cash availability and investment capability are constraints. Hence the company is always on the lookout for more orders for which it must have better due date performance compared to the competitors in the SME sector.

For the company, the customer demand keeps on changing every month, along with the uncertainties of casting supplies, machine breakdowns, worker absenteeism, quality problems, electricity failure etc. Hence the initial production schedules are rarely followed on the shop floor and there are always schedule expeditions at the middle or at the end each month. Because of the uncertainties involved as mentioned above, the priorities for the orders constantly change and at the end of each month, there are always some orders which get delayed. Moreover, there is no specific method on the shop floor which can prioritise the orders. As a fact maintaining a good due date performance becomes difficult for the company. If the orders are frequently delivered late, the company is underrated by the OEMs and there is loss of sales and business with them. Presently the company is able to meet 65% of due date on an average, which the company wants to enhance further to gain competitive advantage.

Due to presence of many problems and lack of proper scheduling of orders, the company is unable to maintain the due date performance that directly impacts the company’s ability to increase its sales and thus the profit. However, due date performance depends upon how well a company schedule its production and manage its constraints.

Based on the above investigation, a number of undesired effects (UDEs) have been identified that ABC has been facing. The identified UDEs are then connected using cause-effect logic to develop the current reality tree that helps identify the core problem(s) as shown in Figure 1. The core problem(s) is the one which is the main cause of all the UDEs. The figure clearly indicates that the company’s problem lie in the inefficient scheduling process. Therefore, to solve the issues mentioned above and synchronize the material flow through the system, the approach of DBR scheduling seems more appropriate as a competitive operations strategy.

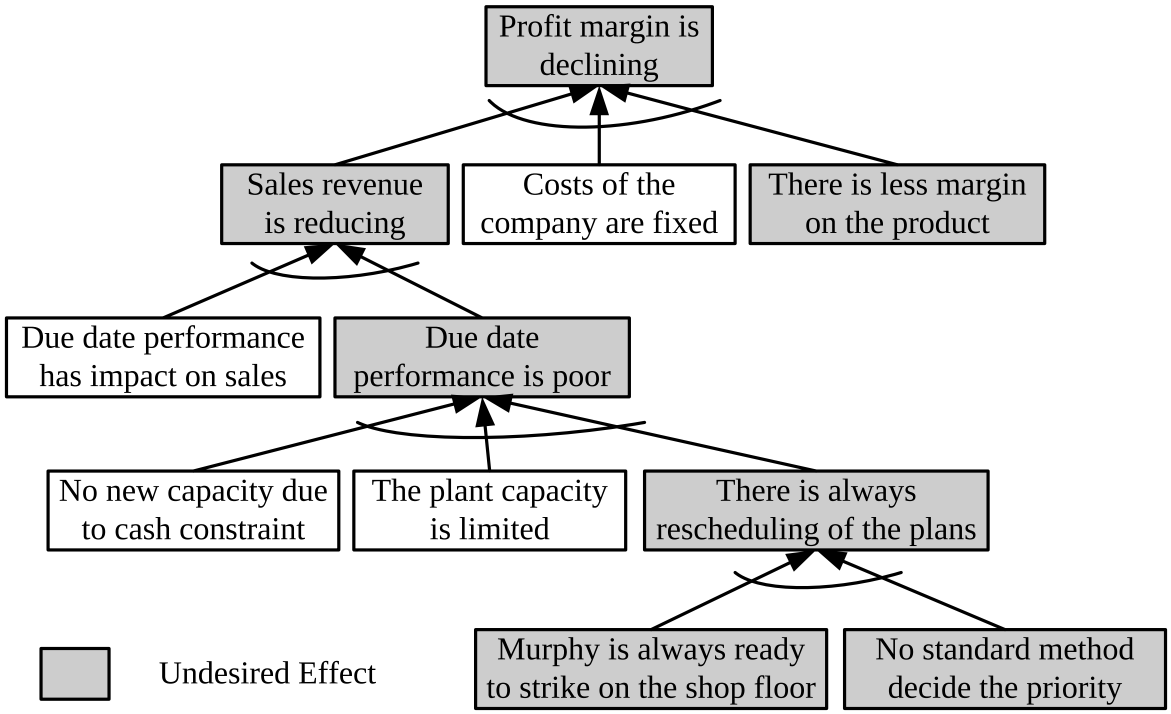

Figure 1 The current reality tree (CRT) for the SME

4.0 Drum-Buffer-Rope (DBR) methodology

The various tools and techniques of TOC are based on the five steps of Process of On-going Improvement (POOGI) that are (a) identify the system constraint(s), (b) exploit the constraint(s), (c) subordinate all other decisions to step-b, (d) elevate the constraint and the last stage is, not to let inertia become the system's constraint. However, according to some authors, the DBR is the application of the first three steps only that creates the DBR schedule (Chakravorty and Atwater, 2005).

The name DBR comes from three essential elements: the drum (the schedule for the constraint), the buffer (the material release duration) and the rope (the release timing). A constraint is defined as the weakest resource in the system that restrains the system's capability to increase revenue.

The drum refers to the schedule developed for the constraint resource that exploit its available capacity and decide the rhythm of pace of the system (Atwater and Chakravorty, 2002; Hasgul and Kartal, 2007). One of the reasons to develop the drum schedule is that every minute lost at the constraint resource is lost forever and the system can't produce more than the constraint resource.

Daily perturbations (machine breakdown, electricity failure, non-availability of material, worker absentisum etc.) occurring at non-constraint resources can disrupt the entire system, the drum and the shipping schedule. In order to ensure that these fluctuations do not adversely impact order due dates, three time buffers viz. *constraint buffer, shipping buffer* and *assembly buffer* are introduced into the systems depending upon the location of the constraint(s), the particular controlling points and the requirement of protection (Ye and Han, 2008).

The *constraint buffer* is placed just before the primary CCR that protect the CCR from disturbances occurring in the processes preceeding to it to ensure that it meets the drum schedule on time. This time buffer is a liberal estimation of the manufacturing lead time from the release of raw material to the site of CCR including some safety margin. It helps in determining the release schedule of raw materials that pass through the CCR. The *shipping buffer* is placed at the end of the production system to protect the shipping of finished goods. This buffer takes care of any disturbances occurring at the CCR and in the processes which follows the primary CCR till the production of finished goods (Chakravorty, 2001; Chakravorty and Brian, 2005). It helps determining the initial schedule for the constraint and establishing the release schedule for the raw materials that do not go through the constraint or assembly buffers. This time buffer is the liberal estimation of the manufacturing lead time from the CCR to the completion of an order.

The *assembly buffer* is placed just before the assembly operation of a production line. This buffer ensures that those assembly operations which are directly fed by the constraint do not wait for material to arrive from non-constrained legs within the flow. The size of this buffer is a liberal estimation of manufacturing lead time from the release of raw materials to an assembly point where CCR parts and non- CCR parts are assembled (Schragenheim and Ronen, 1990). These buffers of proper sizes are intended to allow a limited accumulation of WIP, sufficient to provide protection against variability in the preceding operations (Simons et al., 1999).

The next element of the DBR scheduling system is the *rope*. There are two types of ropes, shipping and material release ropes. The shipping rope connects the shipping buffer to the constraint schedule (drum) whereas the material release rope connects the drum with the tactical or material release gate. The overall purpose of the rope is to synchronize material flow through the system taking care of the order due dates. The ropes help to maintain required amount of inventory in the production system by introducing the raw material at appropriate times. This very idea of tying all the relevant dates together is similar to that of the rope analogy.

Identifying the system constraint, placing buffers, setting appropriate buffer sizes, developing the drum and the release schedules are a part of the DBR planning. However the crucial part of the DBR is executing the plan or controlling the system through monitoring the buffers on continuous basis. Another important aspect of DBR schedule is that a process batch is not necessarily equal to a transfer batch (Sipper and Bulfin, 1997). The transfer batch helps to move sub-set of the entire production lot (production batch) to downstream machines. Thus this technique helps the system to allow a degree of simultaneous production of an order on different machines (Vickson and Alfredsson, 1992). Overall, the DBR solution protects the weakest link in the system and therefore the system as a whole, against process dependency and variation and hence maximizes the system's overall effectiveness. The next sections explain the details of the planning and execution phase of DBR approach in a SME industry

5.0 Application of DBR

ABC produces a number of products, however for implementing DBR approach only 10 products P1 to P10 were considered. The reasons are (a) these products are critical to the OEMs in the term of due date performance, (b) their demands are more uncertain, and (c) ABC cannot outsource these products and their sub-assemblies and components, (d) these products generate higher throughput for ABC. The throughput for each product was calculated as selling price minus total landed material cost. The selling prices, monthly demands and raw materials required with their landed costs were considered are shown in Table 1. The company receives the order for the ten products from the OEMs, one week before each month.

Table 1 The selling prices, monthly demands and raw materials required with their landed costs for the ten products

Selected Product	Selling price (Rs.)	Monthly demand (Mean, SD)	Raw material used (material cost (Rs.))	Total landed material cost (Rs.)
P1	1897	110,20	RM1 (256), RM2 (783)	1039
P2	1193	60,10	RM3 (350), RM4 (339)	689
P3	834	110,20	RM5 (313), RM6 (43)	356
P4	638	250,80	RM7 (309), RM8 (10), RM9 (28), RM10 (100)	447
P5	616	200,50	RM11 (201), RM12 (68), RM13(154)	424
P6	770	200,10	RM14 (20), RM15 (122), RM16 (30), RM17 (314)	486
P7	871	120,25	RM18 (337), RM19 (100), RM20(120)	557
P8	692	310,80	RM21 (100), RM22 (140), RM23(234)	474
P9	3200	20,5	RM24 (700), RM25 (350), RM26 (494)	1544

P10	260	125,15	RM27 (160), RM28(45)	205

To decide the monthly demand patterns for the products as shown in the third column of Table 1, the demand data for the products over the past 3 years were collected. Based on collected data, it was observed that each demand pattern follows normal distribution and thus mean and standard deviation (SD) were calculated.

Next, to observe the flows of products on the shop floor, a number of field visit were done. The field visits showed that the products flow through different resources and the production flow of each product is of almost A-Type, converging to a single assembly unit. On the shop floor, there are 14 different resources like A1, A2…M1, where variety of operations are performed. Most of the resources are automated machines including assembly operations. ‘The product flow for each product was then depicted using product flow diagram as shown in Figure 2. The product flow diagram shows the number of operations, the sequence in which the operations are carried out or the final product is made, the resources used, resource contention and bill of material. For instance, the product flow diagram for product P1 (Figure 2a) shows that there are five sets of operations that are performed at the five different resources and two types of raw materials (RM1 and RM2) are used and processed through these resources.

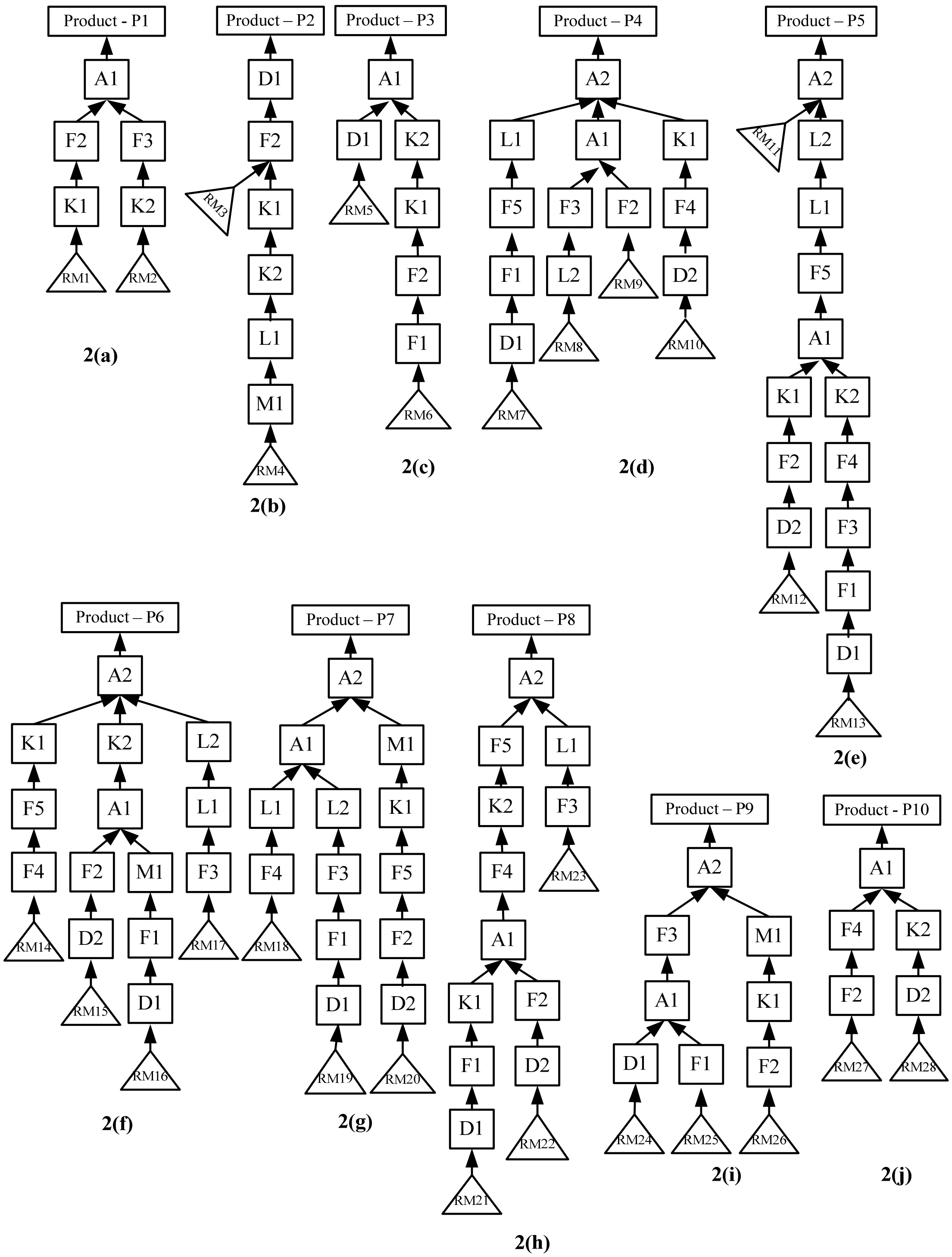

Figure 2 Product flow diagrams for the products P1 to P10

In the field visits, the processing times at different resources for each product were also noted as shown in Table 2. Table 2 shows types of resources used and number of available resources in each type. Available working hours per shift is generally 8 hours starting from 10.00 am to 6.00 pm, however it is less in case of planned shutdowns. The total working days in a month are 25 days and hence the total working hours in a month are 200 hours.

Table 1 Processing times(minutes) for the products on different resources

Product Code	Type of resource													
	A1	**A2**	**D1**	**D2**	**F1**	**F2**	**F3**	**F4**	**F5**	**K1**	**K2**	**L1**	**L2**	**M1**
P1	15	0	0	0	0	46	40	0	0	2	10	0	0	0
P2	0	0	50	0	0	37	0	0	0	16	14	52	0	48
P3	6	0	1	0	2	6	0	0	0	10	4	0	0	0
P4	4	11	20	17	10	3	17	2	5	2	0	10	67	0
P5	4	6	10	15	10	3	17	2	3	2	4	5	34	0
P6	6	5	11	16	10	3	5	2	4	2	7	5	19	35
P7	6	5	13	13	10	11	5	2	4	2	0	5	19	38
P8	4	8	19	16	10	13	17	2	4	2	0	6	0	0
P9	10	40	7	0	25	7	42	0	0	8	0	0	0	26
P10	6	0	0	13	0	12	0	2	0	0	5	0	0	0
Setup Time	1	2	2	1	12	2	1	3	1	2	1	4	3	1
Available resources	1	1	3	3	2	3	3	1	1	1	1	2	3	2

5.1 Planning part of the DBR

The first step of implementing the DBR approach is to identify the constraint resource(s). With the monthly demands for the products following the normal distributions as shown in Table 1, the company environment was simulated 1000 times and the potential constraint resources were found out using load analysis. The potential constraint resources thus obtained are resources A1, A2 and L2, out of which resource L2 becomes capacity constraint resource for 75% of times. At a time, one of the three potential constraint resources is active for a particular demand pattern in a given month. The active constraint for the given month could be found out using Equation 1.

The active constraint (AC) = $\{ j : Max(U_j) \}$ (1)

Where

$Uj = \sum_{i=1}^{10}(Xi * Pij)/(200 * Nj)$

Here

i = Products {1, 2……, 10}

j = Constraint resources {A1, A2, L2}

U_j = Utilization of j^{th} constraint resource

X_i = Demand for the i^{th} product in the given month

P_{ij} = Processing time of product i at j^{th} constraint resource in minutes

N_j = Number of j type constraint resources available.

One of the reasons to develop Equation 1 was that any schedule developer on the shop floor could use the equation and identify the potential constraint resource among the three resources A1, A2 and L2. Identification of the constraint resource would help the scheduler to place the time buffers (*constraint, assembly and shipping buffers*) and set their sizes appropriately.

For each of the three scenarios possible based on the three potential constraints, the product flow diagrams (Figure 2) of all the products were observed. The products requiring the constraint buffer and the assembly buffers were then identified along with the locations of the buffers in the system as shown in Table 3. For instance, in one of the scenarios where the resource A1 comes out to be the active constraint, all the products except product P2 pass through the constraint resource A1. Therefore a common constraint buffer was placed before the resource A1 for all the products except product P2. In the same scenario, all the assembly buffers were identified observing the product flow diagrams and were placed after the appropriate resources. However, if a resource is common to more than two products, only one assembly buffer is placed after the resource. For instance, in the scenario where resource A1 becomes the constraint, only four assembly buffers are located for products P4, P6, P7, P8 and P9. Moreover, if resource A2 becomes the constraint resource, there is no need of placing any assembly buffers on the shop floor since only last operations of the products are carried out at resource A2. In the case of placing shipping buffer, only one shipping buffer was placed for the all products at the of production.

Table 3 The products passing through the constraint resource and assembly buffers with their locations in the three scenarios

Potential constraint resource	Products passing through the constraint resource	Assembly buffers required for the products and their respective locations
A1	P1,P3,P4,P5,P6,P7,P8,P9,P10	P4(L1,K1), P6(K1,L2), P7(M1), P8(L1), P9(M1) (Total assembly buffers = 4)
A2	P4,P5,P6,P7,P8,P9	-
L2	P4,P5,P6,P7	P4(F2,L1,K1), P5(L2), P6(K1,K2), P7(L1,M1) (Total assembly buffers = 6)

Once the buffers are located, the next crucial stage is to set appropriate sizes for them. For any scenario there is only one constraint buffer but there could be more than one assembly buffers as shown in Table 3. For calculating the constraint buffer size in a particular scenario, all the legs starting from the first operation where the raw material is used to the operation that is performed at the constraint resource were considered and the one leg with the maximum time (sum of setup times + 20 * sum of processing times) was chosen. The size of the constraint buffer was then set to this maximum time. Similarly for estimating the assembly buffer sizes for all the assembly buffers in a particular scenario, all the legs starting from the first operation where the raw material is used to the assembly operation were considered and the one leg with the maximum time(sum of setup times + 20 * sum of processing times) was chosen. The buffer sizes of all the assembly buffers were then set to this maximum time. Moreover, for estimating the shipping buffer size in a particular scenario, all the legs starting from the operation that is performed at the constraint resource to the end operation that is performed on the resource A2 were considered and the one leg with the maximum time (sum of setup times + 20 * sum of processing times) was chosen. The size of the shipping buffer was then set to this maximum time. In the calculations, the number 20 indicates the process and transfer batch sizes for the products.

Before implementation of the DBR solution, the process and transfer batch sizes in a month for the products were same and equal to the demands of the products in that month. This wrong decision of ABC resulted in a huge work in process inventory on the shop floor and created many problems. To overcome this, the critical analysis of the material handling system was carried out and based on the analysis, it had been advised that ABC should process and transfer the materials in the batches on 20 using small containers on which a detailed information must be pasted including the sequence in which the products are made, priority of the products and their due dates. This action resulted in drastic reduction of work in process inventory and a smooth flow of materials on the shop floor without any problems.

Let us consider the situation where the demand pattern for the month is given as $X_1 = 90$, $X_2 = 68$, $X_3 = 103$, $X_4 = 315$, $X_5 = 164$, $X_6 = 206$, $X_7 = 87$, $X_8 = 282$, $X_9 = 13$ and $X_{10} = 115$. Under this situation, using Equation (1), L2 comes out to be the constraint resource. If resource L2 becomes the active constraint resource, one constraint buffer and total six same size assembly buffers for products P4,P5, P6 and P7 need to be placed. To decide the buffer sizes, the product flow diagrams are observed and the leg of product P5 joining the operation performed at resource L2 and RM 13 comes out to be the maximum time leg. The size of the constraint buffer is thus decided to be 30.5 hrs. which with some liberal approximation is taken as 4 days (32 working hrs.). Similarly, for deciding the assembly buffer size, the leg in the product P6 joining the operation performed at resource K2 and the RM 16 comes out to be the maximum time leg. The assembly buffer size thus comes out to be 22.55 hrs. which with some liberal approximation is taken as 3 days (24 working hrs.). Moreover, to decide the shipping buffer size, the leg in the product P4 joining the operations performed at resource L2 and resource A2 comes out to be the maximum time leg. The shipping buffer size thus comes out to be 14.6 hrs. which with some liberal approximation is taken as 2 days (16 working hrs.). If A1 becomes the constraint resource the constraint, assembly and shipping buffers sizes were estimated as 18 hrs, 24 hrs and 16 hrs. respectively whereas in the case of A2, the constraint and shipping buffer sizes were set to be 32 hrs and 16 hrs respectively as resource A2 becomes that active constraint, there is no need of assembly buffers.

After placing the time buffers and appropriately setting their sizes, the next step is to decide priorities for the products to be processed at the constraint resource. Under the three scenarios, the priorities for the products were decided based on products' throughput per constraint minute as shown in Table 4 that shows there are some free products which do not pass through the constraint resources.

Table 4 Products priority under the three scenarios

Products	Priorities under the scenario where constraint resource is		
	A1	A2	L2
P1	4	Free product	Free product
P2	Free product	Free product	Free product
P3	3	Free product	Free product
P4	8	6	4
P5	7	4	3
P6	9	2	2
P7	6	1	1
P8	5	5	Free product
P9	1	3	Free product
P10	2	Free product	Free product

After setting the priorities, the next step is to develop the schedule (drum) for the constraint resource. Here, for the illustration purpose the same scenario (constraint resource L2) has been considered where only four products P4, P5, P6 and P7 pass through the constraint resource L2. So the drum schedule has been developed for the four products considering their priority as shown in Table 4. Other products are free products and there is no need to involve them in the drum schedule.

Table 4 The drum schedule if resource L2 becomes the active constraint resource

Priority	Products to be scheduled	Demand	Processing time* (minutes)	Total processing time (hours, minutes)	Start time	Finish time
4	P4	315	22.3	117, 00	Day9 13:00	Day23 18:00
3	P5	164	11.3	31, 00	Day5 15:00	Day9 13:00
2	P6	206	6.3	21, 30	Day2 17:30	Day5 15:00
1	P7	87	6.3	9, 10	Day1 16:20	Day2 17:30

*Note :- The processing times are 1/3 of that given in Table 2 as there are 3 L2 resources.

After developing the drum schedule, the raw materials passing through the constraint resource, the assembly buffers and required for the free products are released at appropriate times. The material release schedule for the raw materials passing through the constraint resource is developed by backward calculation subtracting the constraint buffer time from the drum schedule whereas the raw materials passing through the assembly buffers are also released by backward calculation subtracting assembly buffer from drum schedule as shown in Table 5.

Table 5 The material release schedule for the raw materials passing through the constraint resource and assembly buffers if resource L2 becomes the active constraint

	Products	Raw Material	Demand	Release Time
Material passing through the constraint resource	P4	RM 8	315	Day5 13:00
	P5	RM 12, RM 13	164	Day1 15:00
	P6	RM 17	206	Day-2 17:30
	P7	RM 19	87	Day-3 16:20
Material passing through the assembly buffer	P4	RM7,RM9,RM10	315	Day6 13:00
	P5	RM11	164	Day2 15:00
	P6	RM14,RM15,RM16	206	Day-1 17:30
	P7	RM 18,RM20	87	Day-2 16:20

As the process and transfer batches were predefined, the raw materials required for the free products were also introduced in the batches of 20. To avoid unnecessary inventory on the shop floor, the batches were introduced in to the system evenly in Di/20 time intervals as shown in Table 6. However, the last batch can be less than 20 depending upon whether Di/20 is fraction or integer. In this case the last batch that is less than 20 is released on the next interval. For instance, if demand for a product is 110 i.e. the ratio Di/20 is 5.5, the raw materials for the products are released in batches of 20 in five intervals and in the sixth interval 10 units are introduced.

Table 6 The release schedule for the raw materials required for the free products if resource L2 becomes the active constraint

Products	Raw materials	Demand	No of intervals (Di/20)	Days, the last day (the quantity released)
P1	RM1, RM2	90	5	1, 6, 11, 16, 21(10)
P2	RM3, RM4	68	4	1, 7, 13, 19(8)
P3	RM5, RM6	103	6	1, 5, 9, 13, 17, 21(3)
P8	RM21, RM22, RM23	282	15	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15(2)
P9	RM24, RM25, RM26	13	1	1(13)
P10	RM27, RM28	115	6	1, 5, 9, 13, 17, 21(15)

5.2 Execution or control part of the DBR

Planning phase of the DBR locates constraint, assembly and shipping buffers, decides initial buffer sizes and develops drum, shipping and raw material release schedules. The second part of the DBR is the execution or control aspect of implementation, also referred to as buffer management that signals the need to adjust a given buffer size, provides real time prioritization of work orders and helps determine continuous improvement efforts. In buffer management the buffers are divided equally into three zones green, yellow and red. If an order penetrates in the green zone, the order reaches the required place too early. If the order penetrates in the yellow zone, we are still in safe zone; however we have to track the status of the order on the shop floor. Penetration of the order in the red zone gives a signal of taking an immediate action to move the order to the concerned place. In other words, the green zone is the watch zone, the yellow zone is the tracking or monitoring zone and the red zone is the expedite zone of the buffers. If most of the orders are in the green zone then the initial buffer size is too high whereas if most of the orders penetrate in the red zone means the initial buffer size is too small. Hence, based on the buffer penetration the buffer sizes are reset by some amount say ±10%.

To demonstrate the execution part of the DBR, one of the three scenarios where L2 comes out to be constraint resource is considered. In this scenario, the sizes of constraint, assembly and shipping buffers were estimated as 4 days(32 Hrs), 3 days(24 Hrs) and 2 days(16 Hrs) respectively. As per the buffer management approach, these buffers were divided into three zones namely green, yellow and red as shown in Table7. The red zones of the buffers were kept smaller sizes than green zones since most of the resources are automated machines and take less time to repair.

Table 7 Division of the constraint, assembly and shipping buffers into three zones

Buffer type	Buffer size (hrs)	Green zone (hrs.)	Yellow zone (hrs.)	Red zone (hrs.)
Constraint	32	12	10	10
Assembly	24	8	8	8
Shipping	16	6	6	4

To check feasibility of the buffers those were set initially, the shop floor of the company was visited and observed for a period of 6 months. All the resources were tracked for this duration and data were obtained in terms of resource availability and mean time to repair (MTTR) as shown in Table 8.

Table 8 Resource availability and mean time to time repair (MTTR)

Resource	Resource availability	Mean time to repair time (MTTR)(Minutes)
A1	95%	1
A2	96%	1.5
D1	89%	1
D2	91%	1
F1	92%	2
F2	95%	2.5

F3	90%	1.5
F4	95%	2
F5	85%	1
K1	92%	1
K2	92%	2.5
L1	88%	3
L2	95%	1
M1	95%	1

Considering the shop floor environment and the percentage availability of the resources shown in Table 8, the environment was simulated with the demand scenario of past six months. After simulating the environment, the buffers were observed. It was found that most of the times the constraint buffer comes out in yellow zone and thus the constraint buffer size is appropriate. However assembly buffer came out to be in red zone most of the times. Since assembly buffer is in red zone, the appropriate action is to increase the buffer size. The table below shows the percentage times the buffers were in green, yellow, and red zone under the simulated environment with past 6 months order.

Table 9 Percentage times-zone wise division of buffers under simulated environment.

	Constraint buffer	Assembly buffer	Shipping buffer
Green	0	0	0
Yellow	84%	34%	66%
Red	16%	66%	34%

Depending upon the situation of the buffers for the latest orders, it had been advised to ABC that proper resizing of these buffers could be done for the future orders. If the order penetration is in yellow zone, the buffer size is considered to be appropriate and if the penetration is in red or green zone proper action is needed as mentioned earlier. However it is not always necessary to resize the buffer if it is in red zone or green zone. It was advised to the company that if buffer is in red zone and more than 70 % of red zone is covered, the buffer size could be increased by 10-

12 %. Similarly if a buffer is found to be in green zone and less than 30 % of it is covered then buffer size could be reduced by 10-12 %.

Although for a DBR implementation proper buffer sizing and resizing is indispensable part of the process, it is also important to look for the causes of a buffer coming in red zone. Various wrong practices on shop floor could lead to improper utilization of resources and in turn getting buffers exhausted. A constraint buffer coming in red zone could be because of many reasons. It was found that on shop floor constraint resource is idle many times. Ensuring full utilization of constraint resource ensures maximum benefits of a constraint buffer. It was also found that quality check was being done after the constraint resource, which was causing constraint resource to work on some defective items. It was advised to the company to do quality check before the constraint resource thus ensuring it to work on good parts only. The tool changing process was found to be inefficient and took more time because of mismanagement of changeover. Saving time on such kind of activities saves time of the constraint resource and thus ensures full utilization of it. Assembly resources like A1 and A2 are being involved in most of the products and thus required most of the changeovers. Every time a changeover happens it takes a lot of time since only one operator was assigned to these resources. It was advised to the company to assign one more operator to ensure the quick changeover thus saving time of assembly resource which in turn ensures proper use of buffers.

Other observations regarding operator absenteeism, electricity failure and delay in raw material supply were also obtained. Operator absenteeism is one of the causes of concern for the company. With no prior notice operators were absent on quite a few occasions. It was also observed that sometimes no operator is there on the constraint resource leaving it to be idle. This happened especially at the break time. Electricity failure is not a major concern as the company is well backed with secondary sources of power. For most of the raw materials supplier reliability is good and the materials are on time. However there are few raw materials for which delay in supply is quite frequent. This in turn causes delay in the supply of some resources on shop floor and delay in completing the orders. In the case of operator absenteeism, it was advised to the company that it should ensure full utilization if the constraint resource appointing a dedicated employees all the time. With respect to delay in raw material supply, it had been advised to the company that it should primarily ensure supply of raw materials feeding to the constraint resource and secondary should focus on the material passing through the assembly buffers.

As we have seen under the execution phase of the DBR implementation, the most important exercise is to observe all the three buffers i.e. constraint, assembly and shipping. Appropriate actions should be taken depending upon in which zone the buffer lies. Being a SME company it is not possible always to make use of costly DBR software and thus require an easy manual tracking of the buffers. A table given in Appendix- I was provided to the company wherein they could maintain the arrival of products at the various buffers locations. With the help of the record, buffer use can be calculated and depending upon in which zone the buffer lies appropriate action can be taken.

To make execution part of the DBR solution more realistic, ABC had been advised to assign a buffer manager for maintain buffer management worksheet which could be attached to the small proposed containers. Whenever the cause of an order’s lateness is detected, it is placed on the buffer management worksheet which would help to overcome such causes to execute the future orders. If the buffer manager is in a dilemma of deciding priorities, he can use the priorities set for the orders or the measure '*throughput dollar days*'.

Conclusion

Small and medium enterprises face various problems. And, they always want a simple solution to tackle various problems penetrating quickly at operations level. In this paper the solution used to overcome all the problems of the SME in manufacturing environment is the Drum-Buffer-Rope technique of TOC. Applying the DBR technique, the changing environment of demand was tackled through finding out the potential constraints. Buffering at various locations overcame murphy on the shop floor. Priorities for the orders were predefined and did not change throughout a month. Operations and material flows were better synchronized that resulted in drastic reduction in inventory on shop floor. Rejections and reworks were reduced. The schedule planners were tension free as DBR made the production scheduling process very simple and proper. While planning and executing the DBR, a number of decision were taken for improvements in the existing system related to material handling, quality check, tool changeover process etc. Consequently, the company has improved its due date performance from 65% to 95%. The improvement in performance resulted in more orders from OEMs and reduction in overall cost resulted in more profit to the company. As a result, DBR acted as a competitive strategy to the company to overcome all the problems of the SME.

Although the company has improved its performance, there is still the scope for improvement. Sometimes the demand of free products is too high and it becomes complex to handle it along with priority products. In such cases the company can outsource the production of such extra demand. Recently company has been receiving orders in the middle and at the end of a month, in such cases S-DBR can give far more good results as compared to DBR. To improve due date performance further, the company can also integrate various lean tools like 5S, Kaizen, Single minute exchange of die (SMED), PDCA (plan, do, check and act), Kanban, total productive maintenance (TPM) and six sigma with the DBR.

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Appendix-I

A worksheet for monitoring constraint, assembly and shipping buffers

If the constraint resource is	Products	Time to reach the constraint resource* (min)	Time to reach assembly operation** (min)						Time to finish production*** ((min)
			F2	K1	K2	L1	L2	M1	
A1	P1								
	P2								
	P3								
	P4								
	P5								
	P6								
	P7								
	P8								
	P9								
	P10								
A2	P1								
	P2								
	P3								
	P4								
	P5								
	P6								
	P7								
	P8								
	P9								
	P10								
L2	P1								
	P2								
	P3								
	P4								
	P5								
	P6								
	P7								
	P8								
	P9								
	P10								

*Indicates the constraint buffer

** Indicates assembly buffer

***Indicates shipping buffer