An approach to manage constraint resource and outsourcing decision

P S Chakraborty 1,*, G Majumder 2 and B Sarkar 3
1 Adult, Continuing Education and Extension Department, 2 Mechanical Engineering Department, 3 Production Engineering Department, Jadavpur University, Kolkata 700 032

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Constrained resources in manufacturing organization lead managers to take decision on outsourcing of some products. This paper compares the possible solution between normal accounting, theory of constraints (TOC) and extended TOC to decide production outsourcing. This paper is a real life implementation of linear programming with TOC philosophy, which is easier to follow with very few parameters required for verification. Extended TOC model is simple and helps managers to make faster decision in outsourcing problem with maximum throughput.

Keywords: Experience curve, Linear programming, Normal accounting, Theory of constraints, Throughput
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Introduction

Manufacturing organization encounters the situation of surplus demand than the capacity to manufacture. It is policy to supply all the market demand in order to prevent other major competitors from penetrating into its strong market area also to maintain reputation for on time delivery. Normal accounting (NAC) procedure with associated difficulties has been discussed in depth 1-3. Out of numerous theory-of-constraints (TOC) 4 related review, some specific fields are focused on to develop and align performance measurement system of different functions to improve process, product and profit. One research stream has stressed on throughput accounting 5-8. Another research stream worked on TOC with traditional cost accounting and activity based cost management 9-11, and production management related aspect analysis 12-16. These papers focus mainly on manufacturing facility inside the organization. Linear programming (LP) with TOC concept 14-15 has been suggested. LP extension of TOC 17 with a constructive model was also suggested to view the problem with greater extent by covering suppliers. This case study analyses effect of experience curve in business process and finally decides about outsourcing problem under constraint situation in a factory based at Kolkata, India.

Theory of Constraints

TOC helps managers to maintain a focus on system constraints and proposes a set of principles and concepts to manage the constraints. TOC concept is conceived on three simple performance measures: 1) Throughput (T), the rate at which the system (organization) generates money through sales; 2) Inventory (I), is actually investment made on fixed assets; and 3) Operating expenses (OE), quantity of money spent by the firm to convert inventory into sales. TOC approach is centered around following five focusing steps for identifying and managing the system constraints: i) Identify system constraint(s); ii) Decide how to exploit system constraint(s); iii) Subordinate everything else to the above decision; iv) Elevate system constraint(s); and v) Go back to step 1, do not allow inertia to be a constraint.

Methodology

All information related to raw material cost, hourly rate, selling price, demand, workflow, working time etc was collected. At first, the effect of experience curve in the business context is shown, and then NAC, TOC and extended TOC are applied. Then NAC, TOC and extended TOC are compared with real life example. All the three models provide different results to the same problem. Under such circumstances, when demand exceeds capacity, this new extended TOC model guides about the exact quantity to be manufactured and quantity to be outsourced.
Extended TOC model follows the TOC 5-step methodology considering suppliers capacity also, while elevating the system constraints.

**Extended TOC Model**

Considering a facility with ‘m’ work centres (1,2,.....j,....m) and ‘n’ product (1,2,...k,...n).

'\( x_j \)' is the capacity per week in min for work center j and '\( y_{kj} \)' is the required processing time in min to process product k by work center j. Where, for product k, raw material price = \( P_k \), market price = \( Q_k \), and market demand = \( R_k \).

Due to capacity constraints, company can manufacture \( O_k \) units of a product k.

So, \( O_k \leq R_k \)

Contractor purchase own raw materials and supply product k at the price of \( V_k \).

Total T for a particular product k = T produced of k in house + T of contracted units of k.

\[
T_k = O_k (Q_k - P_k) + (R_k - O_k) (Q_k - V_k)
\]

For all the products, \( T = \sum_{k=1}^{n} (Tk) - OE \)

Simplifying this,

Objective function \( T = \sum_{k=1}^{n} (Contractor profit) \) + (Neglected portion)

Order is determined by contractor profit per constraint resource minutes.

**Case Study**

Kolkata-based organization manufactures five different types of a particular product (consumer durable) at five different prices as follows: A, 610; B, 586; C, 570; D, 550 and E, 560 rupees. Organization signed a contract with a retail chain to supply approx 10000 units per week, after price negotiation. Total order quantity was 60000 units. Prices offered by the buyer were as follows: A, 573; B, 551; C, 540; D, 517; and E, 529 rupees. The management accepted this offer after in-house analysis as per following terms of reference: 1) Supply shall start after 6 months from the date of signing of the contract and during this period company has to comply with the audit findings by the buyer; 2) These products are to be manufactured in a extended facility in the same premise; and 3) Export product specifications are different from domestic specifications and cannot be manufactured using the same work centers. All the data (raw material cost, overhead, cycle time etc) were recorded during the first month of production.

**Experience Curve (EC)**

Company analyzed the offered price through EC, which differs from learning curve (LC) that describes the observed reduction in the number of required direct labour hours as workers learn their jobs. EC by contrast applies not only to labour intensive situations, but also to process oriented ones on the value addition (Fig. 1). Actually all the related cost per product (labour, power, consumables, management hours etc), except raw materials comes down due to learning effect. Organization experienced 97 percent learning (experience) rate in similar type of jobs in the past. With present demand rate after 6 months, total production will be: A, 150000; B, 195600; C, 40800; D, 46800; and E, 60000 products. EC can be expressed as

\[
C_m = a \times m^{\log k/\log2} \]

where, \( C_m \) = cost of mth product, \( a = \) first product cost, and \( K = \) learning rate.

Out of initial product cost, raw material cost for product was: A, 380.15; B, 362.25; C, 353.70; D, 335.30; and E, 343.70 rupees (Table 1). Remaining costs were expenditure for value addition and profit margin. Operating expenses divided by number of products provides expenditure during value addition, which is Rs 78.05 for each product. Profit was as follows: A, 152; B, 146; C, 138; D, 137; and E, 138 rupees. EC is applicable on the expenditure during value addition. If \( a = 78.05 \), then from Eq. (1), \( C_m \) after 6 months can be calculated as: A, 46.23; B, 45.70; C, 48.95; D, 48.66; and E, 48.13 rupees.
So, after 6 months, price of product A will reduce by Rs 31.82 (78.05-46.23). Similarly, for product B, C, D and E, price reduction will be Rs 32.4, Rs 29.1, Rs 29.4 and Rs 29.9 respectively (Table 1). Costs of products after 6 months are nearly equal to the prices buyer offered (Table 1). This is the basis for the management to sign this contract.

Raw Material Cost for Products

Raw material passes through different internal resources (Fig. 2). Raw materials to manufacture all 5 products were as follows: A, A1-A8; B, B1-B8; C, C1-C8; D, D1-D8; and E, E1-E8 (Table 2). Material passes through total eight types of work centres (WCs), which for certain operations are double (WC2, WC3, WC5, WC7 and WC8) to meet demand. In case of final assembly, there is only one assembly line (WC 1). For all 5 products, basically there are two routes for components ultimately assembled at WC 1. In route 1, component passes through WC 3, WC 2 and assembled at WC 1. In route 2, component passes through WC 8, WC 7, WC 6, WC 5, WC 4 and assembled at WC 1. To manufacture these products, materials passes through various WCs.

Cycle Time

To manufacture ‘A’, raw material A3 at WC3 required 0.28 min (Table 3). Then A3 and A2 combined at WC2 required 0.21 min. Likewise, column 3, 4, 5, 6 represent time taken by various work centres to process B, C, D, E.

Company runs for 6 days in a week and single shift. Overhead expenses per week for the organization were Rs 1604000. Set up time for all the stations on an average taken was 12 min per set up. On any particular day maximum number of set up required is one. Set up time and number of set ups per day is assumed so after analysis of last 6 months data.

Weekly capacity for WCs can be calculated as follows: For two numbers of WC2, at daily 8 h run, total weekly time (480 \times 2 \times 6) = 5760 min. Calculation of weekly setting time is, 12 min per set up, one WC requires one set up, 2 numbers of WC1 = 12 x 2 x 6 = 144 min. Weekly capacity = (total weekly time-time lost due to set ups) = (5760-144) = 5616 min.

### Table 1—Experience curve table

<table>
<thead>
<tr>
<th>Product</th>
<th>Raw material cost, Rs</th>
<th>Initial price (IP), Rs</th>
<th>Profit, Rs</th>
<th>Value addition cost (VI) = weekly OE / weekly total production</th>
<th>Production during 6 months</th>
<th>Value addition cost after 6 months, $C_m = a \times m^b$</th>
<th>Price reduction, PR = $C_m - VI$</th>
<th>Rs</th>
<th>Product cost after 6 months = IP – PR, Rs</th>
<th>Buyer offered price, Rs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>380.15</td>
<td>610</td>
<td>152</td>
<td>78.05</td>
<td>150000</td>
<td>46.23</td>
<td>31.8</td>
<td>578.2</td>
<td>573</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>362.25</td>
<td>586</td>
<td>146</td>
<td>78.05</td>
<td>195600</td>
<td>45.70</td>
<td>32.4</td>
<td>553.6</td>
<td>551</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>353.70</td>
<td>570</td>
<td>138</td>
<td>78.05</td>
<td>40800</td>
<td>48.95</td>
<td>29.1</td>
<td>540.9</td>
<td>540</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>335.30</td>
<td>550</td>
<td>137</td>
<td>78.05</td>
<td>46800</td>
<td>48.66</td>
<td>29.4</td>
<td>520.6</td>
<td>517</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>343.70</td>
<td>560</td>
<td>138</td>
<td>78.05</td>
<td>60000</td>
<td>48.13</td>
<td>29.9</td>
<td>530.1</td>
<td>529</td>
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</table>

### Table 2—Raw material cost for products

<table>
<thead>
<tr>
<th>Work centre</th>
<th>Component</th>
<th>Product A</th>
<th>Cost per unit Rs</th>
<th>Component</th>
<th>Product B</th>
<th>Cost per unit Rs</th>
<th>Component</th>
<th>Product C</th>
<th>Cost per unit Rs</th>
<th>Component</th>
<th>Product D</th>
<th>Cost per unit Rs</th>
<th>Component</th>
<th>Product E</th>
<th>Cost per unit Rs</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC 1</td>
<td>A1</td>
<td>332.00</td>
<td></td>
<td>B1</td>
<td>316</td>
<td></td>
<td>C1</td>
<td>310</td>
<td></td>
<td>D1</td>
<td>292</td>
<td></td>
<td>E1</td>
<td>301</td>
<td></td>
</tr>
<tr>
<td>WC 2</td>
<td>A2</td>
<td>3.55</td>
<td></td>
<td>B2</td>
<td>3.25</td>
<td></td>
<td>C2</td>
<td>3.0</td>
<td></td>
<td>D2</td>
<td>3.0</td>
<td></td>
<td>E2</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>WC 3</td>
<td>A3</td>
<td>2.80</td>
<td></td>
<td>B3</td>
<td>2.8</td>
<td></td>
<td>C3</td>
<td>2.6</td>
<td></td>
<td>D3</td>
<td>2.6</td>
<td></td>
<td>E3</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>WC 4</td>
<td>A4</td>
<td>6.10</td>
<td></td>
<td>B4</td>
<td>5.8</td>
<td></td>
<td>C4</td>
<td>4.8</td>
<td></td>
<td>D4</td>
<td>4.8</td>
<td></td>
<td>E4</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td>WC 5</td>
<td>A5</td>
<td>5.15</td>
<td></td>
<td>B5</td>
<td>5.0</td>
<td></td>
<td>C5</td>
<td>4.8</td>
<td></td>
<td>D5</td>
<td>4.6</td>
<td></td>
<td>E5</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>WC 6</td>
<td>A6</td>
<td>11.25</td>
<td></td>
<td>B6</td>
<td>10.3</td>
<td></td>
<td>C6</td>
<td>10.3</td>
<td></td>
<td>D6</td>
<td>10.3</td>
<td></td>
<td>E6</td>
<td>9.2</td>
<td></td>
</tr>
<tr>
<td>WC 7</td>
<td>A7</td>
<td>10.90</td>
<td></td>
<td>B7</td>
<td>10.9</td>
<td></td>
<td>C7</td>
<td>10.2</td>
<td></td>
<td>D7</td>
<td>10.2</td>
<td></td>
<td>E7</td>
<td>10.9</td>
<td></td>
</tr>
<tr>
<td>WC 8</td>
<td>A8</td>
<td>8.40</td>
<td></td>
<td>B8</td>
<td>8.2</td>
<td></td>
<td>C8</td>
<td>8.0</td>
<td></td>
<td>D8</td>
<td>7.8</td>
<td></td>
<td>E8</td>
<td>7.6</td>
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</tr>
<tr>
<td>Total, Rs</td>
<td></td>
<td>380.15</td>
<td></td>
<td></td>
<td>362.25</td>
<td></td>
<td></td>
<td>353.7</td>
<td></td>
<td></td>
<td>353.5</td>
<td></td>
<td>343.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 2—Process flow

Table 3—Cycle time and capacity utilization

<table>
<thead>
<tr>
<th>Work centre</th>
<th>Time per piece at work centers (min)</th>
<th>Weekly load on work centre</th>
<th>Weekly capacity of work centre</th>
<th>% Utilization of work centre</th>
<th>Capacity after adjustment</th>
<th>% Utilization after adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>WC 1</td>
</tr>
<tr>
<td>WC 1</td>
<td>0.13</td>
<td>0.12</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
<td>2467.0</td>
</tr>
<tr>
<td>WC 2</td>
<td>0.21</td>
<td>0.23</td>
<td>0.22</td>
<td>0.21</td>
<td>0.20</td>
<td>4470.5</td>
</tr>
<tr>
<td>WC 3</td>
<td>0.28</td>
<td>0.24</td>
<td>0.22</td>
<td>0.22</td>
<td>0.24</td>
<td>5109.0</td>
</tr>
<tr>
<td>WC 4</td>
<td>0.18</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.18</td>
<td>3581.0</td>
</tr>
<tr>
<td>WC 5</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>5548.5</td>
</tr>
<tr>
<td>WC 6</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.18</td>
<td>2796.5</td>
</tr>
<tr>
<td>WC 7</td>
<td>0.18</td>
<td>0.18</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>3576.0</td>
</tr>
<tr>
<td>WC 8</td>
<td>0.29</td>
<td>0.29</td>
<td>0.29</td>
<td>0.29</td>
<td>0.29</td>
<td>5959.5</td>
</tr>
<tr>
<td>Total</td>
<td>1.67</td>
<td>1.63</td>
<td>1.57</td>
<td>1.56</td>
<td>1.63</td>
<td>33508</td>
</tr>
</tbody>
</table>

A1, B1, C1, D1,
WC 4 and WC 8 are constrained resource (Table 3). WC 7 is the least utilized work centre. To overcome this suggestion given to management is to run both the WC 8 for 6 days during lunch break by adjusting lunch time for operators of WC 7 to Operate WC 8. Operators of WC 7 need to be trained to operate WC 8. After this, additional 180 min per WC per week for WC 8 is available as company runs for 6 days. As organization is having two numbers of WC 8, total capacity increased by \((180 \times 2) = 360\) min. Overhead expenses remained approx same.

It is conveyed to management that as to simplify this model yield rates, breakdown time is not considered. So in practice, WCs need more time. From column 10 and 11(Table 3), it is clear that after the above adjustments WC 8 become non-constrained. Only WC 5 is constrained by 27.53 %. Total capacities of all WCs available after adjustment were 36864 min (Table 3). Operating expanses is same as Rs 1604000, as adjustment of timing is done only within 8 h of working. Time cost per min working =1604000 / 36864 = Rs 43.51 per min.

### Normal Accounting Analysis

For product cost calculation, first adds raw material prices to manufacture A is Rs 380.15 (Table 2). Then product A consumes 1.67 min (Table 2). Time cost of 1.67 min = 1.67 x 43.94 = Rs 72.66. Product cost is obtained by adding time cost with raw materials cost. Profit per working min for all products can be calculated as profit divided by working min. As per normal accounting, higher profit per working min indicates manufacturing priorities (Table 4).

Thus sequences of priorities are C, D, B, A, and E. One unit of A, B, C, D and E consumes respectively 0.18, 0.17, 0.17, 0.17, 0.18 min of constrained resource (Table 3). After producing all C, D and B, still some constraint resource time available on hand. Next priority is ‘A’ and then ‘E’, both consumes 0.18 min of constraint resource.

‘A’ can be produced in 4455 number only by using constraint resource left after producing C, D and B. Remaining quantity of A and full quantity of E is outsourced. Management intention is to buy finish product. After assessing all parties as per vendor evaluation procedure of the organization, one vendor is short-listed. Management negotiated prices with that vendor and following prices finalized: A, 480.15; B, 452.25; C, 423.7; D, 395.3; and E, 433.7 rupees.

\[
\text{T per manufactured unit of product A} = (573 - 380.15) = 192.85. \text{T per contracted unit of A} = (573 - 480.15) = 92.85. \text{Total product T calculation for A} = (4455 \times 192.85) + (1795 \times 92.85) = \text{Rs} \ 1025812.5.
\]

Similarly, T for other products is calculated. Net profit as per normal accounting is Rs 1869400, (Table 4).

### TOC Analysis

In TOC analyses (Table 5), T per constraint resource min is found out. This is different from NAC, which considers all resources equally. Production priorities were serially B, C, A, D, and E based on T per constraint resource min. Maximum T per constraint resource min got first priority and so on. Production quantities were based on constraint resource availability same as described in NAC procedure.
T per manufactured unit of product D = (517 - 335.3) = 181.7. T per contracted unit of D = (517 - 395.3) = 121.7. Total product T calculation for D = (1900 x 181.7) + (50 x 121.7) = Rs.240315. Similarly, T for other products is calculated. Net profit in that case increased from NAC system by Rs (1934900 - 1869400) = Rs 65500 (3.50 % more).

Extended TOC

In extended TOC model, contractor profit is calculated first for all the models (Table 6). Then contractor profit per constraint resource min is calculated for all the models. Product with maximum contractor earning per constraint resource min got first priorities for inside manufactured. As per contractor earning per constraint resource min, criteria inside manufacturing priorities were A, B, E, C, and D. Others are outsourced after fully exploiting constraint resource as described in NAC procedure. In this case, only portion of product D, C and portion of E need to be outsourced. Products T and net profit is calculated as described in earlier two cases.

In extended TOC model, net profit increased by Rs (2267971 - 1934900) = Rs 333071 (17.21 % more from TOC), and Rs (2267971-1869400) = Rs 398571 (21.32% more from NAC).

**Results**

Extended TOC suggested to manufacture 6250 numbers of A, 8150 of B, 0 of C, 0 of D and 1653 of
E and to outsource 1700 of C, 1950 of D and 847 of E only (Table 7). Similarly, to manufacture and to outsource quantity suggested by TOC and NAC models can be found out (Table 7). After going through this analysis by a cross-functional team, management decided to implement this model under sudden increase in order.

Conclusions
A real life-outsourcing problem was implemented on extended TOC model and outcome of this was compared with normal accounting and TOC model. Normal accounting solution does not consider constraint resource separately; but consider all resources equally. Extended TOC is better for outsourcing rather than TOC, as TOC computes throughput without any alternative production set up. Extended TOC model calculates throughput considering contractor’s production set up also. This can be considered as extension of TOC considering upstream of supply chain i.e. suppliers. Resources constraint at in house may not be constraint at contractor’s end. This enables to elevate the system constraint using non-constraint resources of contractor’s end. Pricing can be bargained on that. This model is simple to use and requires only two variables, contractor profit and work time in constraint resource. A future manager who wishes to outsource needs to consider suppliers also by not focusing on internal resource only. Relative contribution from various product manufactured in house against outsource will not make the model inferior compared to other model discussed. In the worst possible case, throughput may be closer or equal to the TOC solution. It will be better to consider yield rates, maintenance time and set up time during study, as these are having significant impact.

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