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The Application of Theory of Constraints in Manufacturing Outsourcing: A Case Study

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Abstract: This paper presents an in depth study of problems due to outsourcing of manufacturing operations. Influencing factors are identified and relationship between them is defined. The outsourcing problem is formulated using linear programming (LP) and analytical solution is determined using context of theory of constraints (TOC). The model can facilitate decision makers in deciding which products to manufacture in-house or which to outsource. The model assists decision makers by computing an operational ratio without solving LP problem. The final outsourcing TOC-LP model is simple in application and requires the calculation of few variables without sacrificing the accuracy.

Introduction

Manufacturing organisations often operate in conditions where in-house resources constraint their output. Such conditions are categorized by market demand in excess of the organisation's manufacturing capacity. This issue of limited capacity management is investigated throughout the literature. This study analyses condition where market demand is variable and exceeds the organisation's manufacturing capacity. The decision maker needs to decide what products to manufacture in-house or outsource based on demand and cost of manufacturing of the product. The relevant important factors to the in-house manufacturing opposed to outsourcing manufacturing constitute 'cost of raw materials', 'in-house labour costs', 'total product manufacturing/ processing time', 'Number of resources employed in manufacturing product', 'Waiting time at bottlenecks/ manufacturing constraints' and 'Selling price of the product' etc. Researchers have used different models which provide fundamentally different results to decide between in-house manufacturing and outsourcing manufacturing. This study compares cost accounting method with theory of constraints method for decision making between manufacturing in-house and outsourcing. The decision process is started with a formal presentation of the outsourcing problem, proceeding with analysis of the problem using Linear Programming and presenting the outcomes of the models under consideration. The TOC methodology comprised of five steps Constraint-Management-Cycle (CMC) for the identification of constraints and their elevation and can be expressed as a five phase process Adnan *et al.* (2007b).

Stage 1: Identify constraints of specific operations

Stage 2: Analyse current performance and identify root causes

Stage 3: Investigate the constraints to improve operations

Stage 4: Apply feedback to the system to maintain the improvement

Stage 5: Elevate the constraints and check for the next ones

Formulation of Outsourcing Problem

Consider a manufacturing facility has 'N' number of resources manufacturing 'M' number of different products. Let R_j denote resource $j's$ capacity in working time available per week (minutes/ week), and let t_{ij} denote the number of minutes required by the resource j to manufacture product i. The cost of raw material used in product i is denoted by C_{rmi}, market price of the product i is denoted by P_{Mi} and the market demand quantity for the product i is denoted by Q_{di}. Due to capacity constraint, the organisation can only manufacture U_i number of units of product i, where $U_i \leq Q_{di}$. In order to prevent competitors enter the market, organisations satisfy all the market demand and simultaneously maintain an organisation's reputation for due date performance. There the organisation tends to outsource part or complete manufacturing of the product. Let us suppose that the outsourcee (supplier) purchase their own raw material and deliver product i at the price of C_{si}. In order to simplify calculations , the organisations additional expenses such as 'cost of labour', 'energy expenses' and 'cost of financing' are considered as operating expenses or the operating utility C_{oe}.

Linear Programming

A manufacturing company targets to maximise its manufacturing utility from manufacturing in-house and from outsourcing of manufacturing operations. The manufacturing utility is defined as the difference between market price and the cost of raw materials. Manufacturing of U_i units of product i uses a total manufacturing utility of $U_i(P_{Mi} - C_{rmi})$. It is assumed that the company is part outsourcing and to meet market demand the company outsources a quantity of $Q_{di} - U_i$, generating a utility of $(Q_{di} - U_i)(P_{Mi} - C_{si})$ from outsourcing of product i. Hence total manufacturing utility required for product i or the total profit from product i is expressed as $U_i(P_{Mi} - C_{rmi}) + (Q_{di} - U_i)(P_{Mi} - C_{si})$. Utility required for manufacturing M products equal $\sum_{i=1}^{M}[U_i(P_{Mi} - C_{rmi}) + (Q_{di} - U_i)(P_{Mi} - C_{si})] - C_{oe}$.

The total utility from the manufacturing company is restricted by its constraint at resource j and by the market demand for product i. When manufacturing a number of products, the product mix problem can be expressed as:

$$Max \sum_{i=1}^{M}[U_i(P_{Mi} - C_{rmi}) + (Q_{di} - U_i)(P_{Mi} - C_{si})] - C_{oe}$$

Subject to:

$$U_i \leq Q_{di}; i \in \{1, \ldots, M\}$$

$$\sum_{i=1}^{M} t_{ij} U_i \leq R_j \; ; j \in \{1, \ldots, N\}$$

The utility function can be simplified as follows:

$$\sum_{i=1}^{M}[(P_{Mi} - C_{rmi}) U_i + (P_{Mi} - C_{si})(Q_{di} - U_i)] - C_{oe}$$

$$\sum_{i=1}^{M}[(C_{si} - C_{rmi}) U_i + (P_{Mi} - C_{si})Q_{di}] - C_{oe}$$

The above expression implies that ‘product price’, ‘cost of raw material’, ‘total time required manufacturing product’, and ‘labour cost’ are irrelevant to outsourcing decision but relevant to $(C_{si} - C_{rmi})$ and ‘time per product at the constraint resource’. The outsourcing problem should be solved for each situation because in many manufacturing companies there is a single resource constraining the capacity of the whole organisation. That enables prioritising the products for manufacturing in-house and for outsourcing. The outsourcing order is decided by the ratio of the outsourcee profit per resource constraint time (effectiveness of resource utility). The usefulness of the ratio is that the products whose outsourcees are seeking higher profit are of the highest importance to manufacture in-house, and the less greedy the outsourcees for the product, the stronger the incentive to outsource. In case of outsourcing, the standard in-house utility (throughput) per constraint time ratio used by TOC is replaced by outsourcee profit per constraint time.

An Illustration of Outsourcing Decision

Consider a manufacturing facility consisting of five work stations ‘WS1’, ‘WS2’, ‘WS3’, ‘WS4’ and ‘WS5’manufacturing four different products ‘P1’, ‘P2’, ‘P3’ and ‘P4’. The manufacturing facility operates thirty-six hour shift per week (2160 minutes). Table 1 lists the time allocated by each work station in manufacturing every product in minutes.

Workstation	Product ‘P1’	Product ‘P2’	Product ‘P3’	Product ‘P4’	Time/ week	Utilisation ratio
WS1	4	8	6	14	1600	74%
WS2	6	10	13	10	1950	90%
WS3	10	13	8	12	2150	100%
WS4	15	14	11	20	3000	139%
WS5	7	12	9	14	2100	97%
Total time/product	42	57	47	68		

Table 1: Workstation time per product (minutes)

As shown in Table 1, manufacturing 50 unit demand level requires 3000 minutes of ‘WS4’ workstation per week that is equivalent 139% of workstation’s capacity. Workstation ‘WS4’ limits the manufacturing capacity of the manufacturing company.

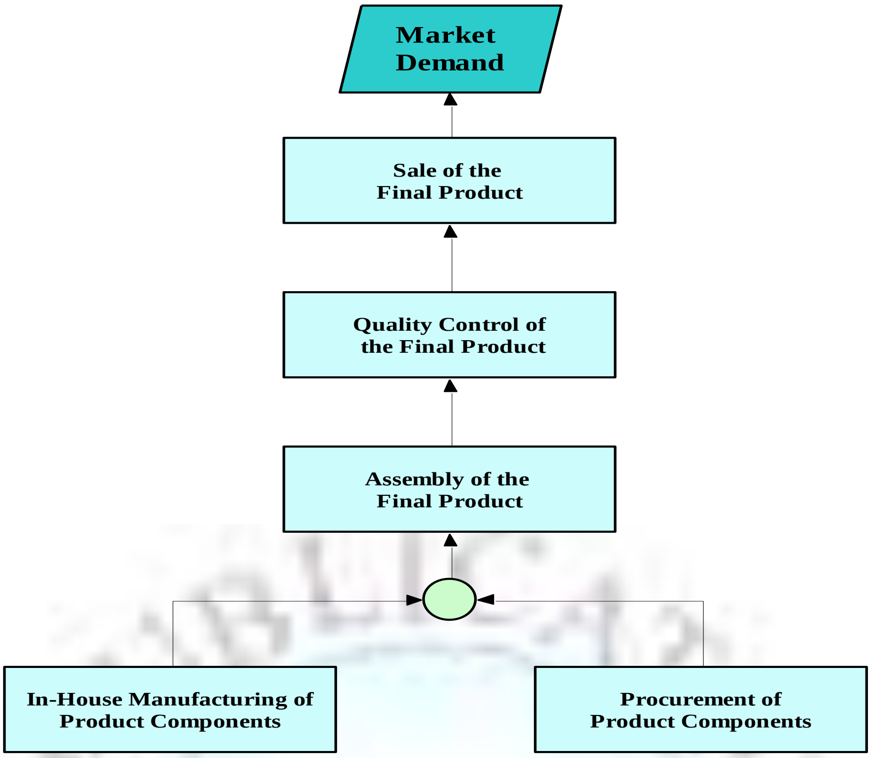

Figure 1: Product Flow Chart

Figure 1 shows the flow layout of the product manufacturing. Each of the four product manufactured uses a number of raw materials. The cost of in-house manufacturing includes 'cost of the raw material', 'cost of labour' and 'cost of quality control' etc. The final product is produced from components manufactured in-house and finished components procured from external sources. The cost of components manufactured in-house for product P1=£150, Product P2=£175, product P3= £200 and Product P4=£150. The cost of the components purchased from external sources for product P1=£100, Product P2=£125, product P3= £150 and Product P4=£100. All the components are assembled to manufacture the end products which are then sold in the market after the quality control is completed. The above problem is analysed according to standard accounting practices. Next the problem is analysed according to TOC using linear programming.

Standard Accounting

Standard accounting process allots preferences to those products which yields more profit per manufacturing time unit. To calculate the profit gain from each product, the company's operating expenses are divided by the number of workstations and by the work minutes per week. Hence, the cost of every minute worked at any workstation equals £20,000/ (5x2160) = £1.85. The cost of each product is the sum of cost of the components manufactured in-house, cost of the components procured from external sources and cost of the total working time at all five workstations. The profit gained per product is calculated by difference in the market price and the manufacturing cost of the product.

Description	Product P1	Product P2	Product P3	Product P4
Total work time / unit product in minutes	42	57	47	68
Cost of the components manufactured in-house/ unit product	£150	£175	£200	£150
Cost of the components acquired through external sources (outsourcing)	£100	£125	£150	£100
Total unit product cost	£250	£300	£350	£250
Product Market price/ unit	£450	£450	£450	£450
Profit per unit product	£200	£150	£100	£200
Product profit per work minute	£4.76	£2.63	£2.13	£2.94
Demand in product units	50	50	50	50
Part products manufactured in house	50	--	--	50
No of product units fully outsourced	--	50	50	--

Table 2: Outsourcing decision based on standard accounting

The product's profit is divided by the total work time in-house invested on the product to determine its profit per work minute (£4.76 for product P1, £2.63 for product P2, £2.13 for product P3 and £2.94 for product P4). P1 is the most attractive product to manufacture since its profit yield per in-house work time (minute) is the highest, followed by P4 and P2, making P3 the least profitable to manufacture in-house. Workstation WS4 will process units of product P1, 50 units of product P2, but no units of product P2 and product P3 due to its time availability constraint. Product P2 and product P3 will have to be outsourced completely. Next step is to compute the utility of the product mix solution. The utility of each product unit manufactured is market price less cost of materials (In case of outsourcing, utility is the market price less outsourcing cost, cost of the material utilised in-house). The utility of each product unit outsourced is evaluated as its market price less the cost of outsourcing. Total product utility is the sum of its in-house manufacturing and outsourced manufacturing utility. The profit is the calculated as the market price less material cost, outsourced cost and operating expenses.

Application of Theory of Constraints

The theory of constraints (TOC) evaluates the feasibility of manufacturing a product in-house or outsource based on in-house manufacturing capacity constraints. Utility for manufacturing a product is defined as the cost of raw material (in-house) and cost of the components acquired from external sources less from its sale price.

Description	Product P1	Product P2	Product P3	Product P4
Product's market price/ unit	£450	£450	£450	£450
Cost of components acquired from external sources	£100	£125	£150	£100
Cost of raw material for in-house manufacturing / unit product	£60	£60	£60	£60
Utility per unit product	£290	£265	£240	£290
Constraint of Workstation WS4 minutes/ Unit product	15	14	11	20
Utility per constraint minute	19.33	18.93	21.82	14.50
Market demand in product units	50	50	50	50
Product units to manufacture in-house	50	50	50	--
No of product units to outsourcee	--	--	--	50

Table 3: Outsourcing decision based on constraints

Product 'P3' has the highest utility per unit constraint time (£21.82/ constraint unit minute), therefore, the first preference to manufacture 50 product units in-house to satisfy market demand. Product 'P1' with a utility per unit constraint time (£19.33/ constraint unit minute) is next. Due to workstation WS4's constraint capacity, 50 units of 'P1', 50 units of 'P2' and 50 units of 'P3' are manufactured in house (part). Product 'P4's ratio is lowest (£14.50/ constraint unit time) and no more in-house manufacturing capacity is left available. The product 'P4' is fully outsourced for manufacturing. The TOC solution exceeds standard accounting in maximising the in-house utility usage by manufacturing 50 units each of 'P1', 'P2' and 'P3'rather than 50 units of each of 'P1' and 'P4'.

Application of Linear Programming

The linear programming is used in defining the outsourcing problem.

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ConstrainedMax 140 U1 □ 165 U2 □ 190 U3 □
  4 U1 □ 8 U2 □ 6 U3 □ 14 U4 □ 2160,
  6 U1 □ 10 U2 □ 13 U3 □ 10 U4 □ 2160,
  10 U1 □ 13 U2 □ 8 U3 □ 12 U4 □ 2160,
  15 U1 □ 14 U2 □ 11 U3 □ 20 U4 □ 2160,
  7 U1 □ 12 U2 □ 9 U3 □ 14 U4 □ 2160,
  U1 □ 50, U2 □ 50, U3 □ 50, U4 □ 50 ,
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The solution to the problem is determined using Mathematica®.

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25870   U1 □ 50, U2 □ 50, U3 □ 50, U
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According to linear programming solution, products P1, P2 and P3 are first to be considered for manufacturing in-house and product P4 with a lower priority. The capacity constraint of workstation WS4 allow manufacturing of 50 product units of P1, 50 product units of P2 and 50 product units of P3 and only 8 product units of P4. The remaining 42 product units of P4 are outsourced to satisfy market demand.

Description (Product units)	Standard Accounting	Theory of Constraints	Linear programming
In-house Manufacturing P1	50	50	50
In-house Manufacturing P2	--	50	50
In-house Manufacturing P3	--	50	50
In-house Manufacturing P4	50	--	8
Outsource Manufacturing P1	--	--	--
Outsource Manufacturing P2	50	--	--
Outsource Manufacturing P3	50	--	--
Outsource Manufacturing P4	--	50	42

Table 4: Comparison of methods

Product P1 is the most preferred for in-house manufacturing for the standard accounting solution, product P3 is the most preferred for in-house manufacturing for the standard theory of constraints solution and product P4 is the least preferred for in-house manufacturing for the linear programming solution.

Conclusion

The paper describes the formulation of outsourcing problem, structures it as a linear programming problem, constructs a simplified criterion for ordering products in terms of preferences to manufacture in house or preference to outsource. The methodologies are simpler to implement. The standard accounting solution does not maximise the in-house resource utility and treats all resources as equal, whereas, Theory of Constraints addresses these limitations and maximises the in-house resource utility. Furthermore, the linear programming is simpler as compared to Theory of Constraints.

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