Using Theory of Constraints in selecting product mix

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Abstract

Theory of Constraints suggests when the product was limited by bottleneck, the best strategy for selecting the product mix is based on the throughput - system performance- in terms of the desired constraint. This issue is not true for products which have been limited by a few quantities. Four realities, which are in opposition to the current thought in TOC literature, have been proved in this article. For instance, the mixed products include some things which have the product lowest margin and the lowest throughput ratio in a limited time and violate marginal and TOC approaches. Such formula constraints which caused by selected mixed products have been proved in this article.

Keywords: Theory of Constraints, product mix, product margin invention, TOC-based inventions, Nature Problem hardness.

Introduction

TOC is a successful operation philosophy which is based on administrator attention concentration on substantial constraints that prohibits complete execution of a seamless system (Goldratt and Cox, 1984; Goldratt and Fox, 1986; Goldratt, 1990a,b). After two decades, many activities have been done by creating Goldartt Institution and TOC Center in Diton, Ohaio. That theory has resulted in creating a group of products such as OPT for optimization, software and the best sales management innovation.

Blackstone (2001) reviewed some of its core idea and studied its application backgrounds. Our study concentrates on the issue of optimum product mix under Theory of Constraints which is regarded as a traditional approach (Gupta *et al.*, 2002; Kee and Schmidt, 2000; Wahlers and Cox, 1994).

Considering the production of a product group regardless of the capacity, by considering the time as a constant horizontal line, requires to demand for all of them. We suppose this capability deals with numerical quantities of final products.

In this case, products should be mixed through evaluating costs priorities of some production line. A traditional method for product mix selection is to prioritize selected products which have higher product margin regardless of considering the elapsed time (Patterson, 1992; Goldratt and Cox, 1984; Blackstone, 2001; Lea and Fredendall, 2000). This method is called traditional marginal approach. In TOC, the goal is to choose product line on the basis of the constraint(s) elapsed time throughput. Throughput is a rate in which the system creates money or the target unit by using and selling it and is obtained through the following relation:

$$Tu=P-TVC$$

In this formula, Tu is each product unit throughput and P is the sale price and TVC is the total variable costs. It means that in constraint, the priority is allocated to products having more throughput and they consume the minimum production time of constraint (Roodposhti, 2007). Thus, the amount of throughput in a minute is the criteria for products manufacturing prioritization.

We introduce this method as heuristic ap-

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proach caused by TOC. The heuristic phrase is described officially in many publications and compilations (Patterson, Goldratt, 1990; Goldratt and Cox, 1984; Blackstone, 2001; Lea and Fredendall, 2002). Fredenda and Lea (1992) suggested selecting product approach after Goldratt and Cox (1984).

Selecting product mix through TOC based creativity

In order to select product mix through TOC-based creativity, the following steps should be taken:

First: Recognizing the system constraints by calculating the necessary capacity in each source to manufacture all products. Constraint or bottleneck is a source which market wants to increase in capacity.

Second: Making decision for how to utilize the system constraints by:

(a) Calculating Contribution Margin Ratio (CM)) for each product in the form of sales price minus raw material (RM) costs.

(b) Calculating CM ratio to product under manufacture in bottleneck source.

(c) In order to decrease the CM/BN ratio for products, make the BN capacity equal to the BN final capacity limit.

(d) Product planning for manufacturing all products which do not need to process time in bottleneck, free product, in order to decrease their CM ratio (Lea and Fredendall, 1997, pp. 1535-1536).

When that theory was suggested, it introduced TOC-based creativity for selecting the best product mix in all cases. For instance, Blackstone suggested extrapolation strategy for sales. What is the best foundation for Sales Commission? Is it one which brings the most beneficial item for the company by emphasizing on wholesale? But, how many companies do you know which are using it? Is the effort for eliminating the constraint as effective as selecting product mix? (Blackstone, 2001, p.1063). Actually, the strategy which gives the best solutions appears when product is considered sectional. Although Plenter (1993) and Lee & Plenter (1993) studies were proved by comparing obtained products mixes through TOC based creativity with something that had been achieved by correct linear programming, this issue was a positive probability for TOC based creativityfailure in finding the optimum product mix when a product should be manufactured with high quantity and under many constraints of product. Those interesting results were a pioneer for some studies uptrend for policies improvement (Feddendall and Lea, 1997; Hsu and Chung, 1998).

Aryanezhad and Komijani (2004) offer a developed algorithm for the case of multiple BNs. Blakrishna and Cheng (2000) question the relationship between TOC and linear programming. Bhattacharya *et al.* (2008) offer fuzzy linear programming method results for the problem. Mishra *et al.* (2005) developed some prohibited researches and simulated hybrid method. Peterson (1992) compares TOC with classic accounting approach. Singh *et al.* (2006) emphasizes on dummy security system principles and behavioral theory which is called Maslow's need hierarchy theory. Finally, Wang *et al.* (2008) use immunization methods such as agreement among members and immunization.

Methods for solving problems with multiple BNs are growing widely. In spite of that, Plenter (1993) proved the weakness points of the creativity of selection approach of the products resulting from TOC fifteen years ago.

Although the situation is more complex than what seems, we will see that the problem has got a high mixed complexity. The goal of this research is recognizing the nature of problem. And, when the NP problem was solved, the question of our investigation is which instruments are recommended to solve this problem. In example, there is no algorithm which could calculate the optimum solution for large cases. We should use advanced innovations. The following realities are directly in opposite to current thought in TOC literature and whatever has been described in this article.

Reality 1: There are some cases which fail even with a bottleneck in TOC based creativity.

Reality 2: There are some cases using TOC-based creativity for obtaining more profit by utilizing traditional approach of product margin failure.

Reality 3: There are some cases in which optimum product mix includes lowest margin products and lowest throughput ratio (system performance) according to each constraint time and violates both traditional approach and TOC based creativity.

Reality 4: There are some reasons which prove that simple access to a desirable and effective mentality is impossible.

Methodology

Reviewing Blackstone case (2001)

Let us start the discussion with an example by Blackstone (2001) such as something depicted in Figure 1.

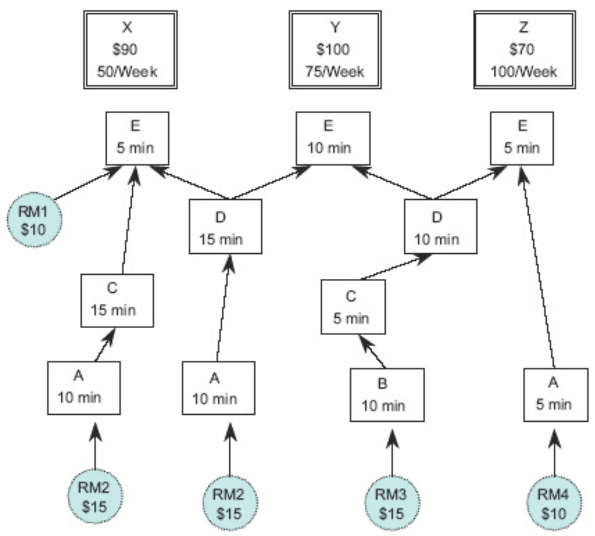

Figure 1. Blackstone 2001, a hypothetical possibility.

State 1: It is assumed that we want to produce three products.

Product X, product Y, product Z. Product X is sold 90$ and its weekly demand is 50 units. Product Y is sold 100$ and its weekly demand is 75 units. Product Z is sold 70$ and its weekly demand is 100 units. We suppose that we have five stations and products have been manufactured in four RMs types (RM1, RM2, RM3, RM4).

X Manufacturing is started by processing two RM2 units in station A and ten minutes for each unit. One of them stays in station C 15 minutes for processing while the other one goes to station D for 15 minute processing. Then, those materials are joined to each other in addition to an RM1 unit and are processed in station D for five minutes. Thus, the material cost for X is 40$.

Product Y is started by processing one unit of RM1 in station A and one unit of RM3 in station B both for ten minutes. After finishing in station A, the resulted material flow goes to station D for fifteen minutes. Then, they go to station E for ten minutes extra processing. Then, the processed RM3 in station B, goes to station C and D for five and ten minutes extra processing respectively. And finally, it is joined to resulted material from RM2 and are processed in station E for ten minutes. As a result, material cost for Y is 30$.

Product Z has comprised from one unit of RM3 and RM4. First, RM3 is processed in station B for ten minutes. Then, goes to C, D and E for five, ten and five minutes respectively and is processed in A for five minutes where it is joined to RM4. Material cost for Z is 25$.

Some readers might have understood that there are some incorrect data in Blackstone article. For instance, state 6 shows that product Z requires fifteen minute processing in station C while his article indicates five minutes. It is impossible to imply that number is correct but it cannot influence the issue.

Therefore, we showed a summary of the system performance in stations in Table 1. It might be concluded that there is not enough capacity in station D which evidently causes the only constraint of the system. Now, a system should be considered. Should products be manufactured? This case shows product mix selection problem under a bottleneck.

System operating costs are as follows: 10$ per hour wage, 30$ per hour for overload which result in 800$ of total cost weekly in five stations for forty hours. If we divide these costs among products, different product margins will appear.

Blackstone (2001) indicated each product wage and overload costs in Table 1. When they are added to RM costs, we can obtain X to Z product margin.

According to traditional approach, Blackstone states that companies intend to high profit margin products which are called «Dogs» and «Stars». This approach is compatible with determining product mix by selecting highest sales margin products as priority.

According to him, a company should prefer to manufacture all demands for 75 units of Y (with 30$ margin). Then, it should produce 52 units of the product which is Z (with 25$ margin) having the best sales margin. These products are only 52 units of total demands for 100 units of Z which could be allocated to BN. Station D is the bottleneck in which five minutes should be considered as the accessible capacity. We might suppose that it is not possible to manufacture any product in this time slot and so this product mix cannot lead to any profit on the basis of margins but it results in 410$ loss (Table 2).

However, this decision, along with its resulted loss, does not offer the actual time which products spend in bottleneck. In that example, the highest sales margin product is the product having the highest profitability as well as in bottleneck. This is a weakness because TOC includes products according to comparing throughput ratio per each minute of constraint. This issue has been clarified through an example in Table 3. Manufacturing product Z with 4.5$/min ratio to achieve total demand of 100 units requires 1000 minutes in BN. The next product is manufacturing product X with 33.3$ to achieve total demand of 50 units which requires 750 minutes in BN. Using the remaining minutes, it allocates the bottleneck heuristic approach to work on product Y and providing a capacity for manufacturing 26 units. Manufacturing that product costs 8.820$ and increases the profit to 820$ weekly.

According to Blackstone (2001), this example proves obviously that those products have no profit for the company. Making decision according to «product profit», while product impact on constraint is not considered, is obviously under the optimization level. The correct decision variable for determining the product mix is throughput per each minute of constraint (Blackstone, 2001, p. 1026). A new product is introduced in the next part of Blackstone's example which let us have a deeper view over the approach of throughput (system performance) per each minute of constraint.

Introducing Product Alpha Pathology

Now, we introduce a new product, product Alpha in Blackstone (2001). In preliminary studies, product Alpha seems to be more different than the previous products. Its parameters is very distinguishable than product X to Z parameters. These differences are investigated precisely in this example in order to introducing constraints.

Table 1. Summary of Blackstone case 2001.

	Each unit capacity needs			Station (Load) (minute)			
	Product X	Product Y	Product Z	Product X	Product Y	Product Z	Necessities sum
Station A	20	10	5	1000	750	500	2250
Station B	0	10	10	0	750	1000	1750
Station C	15	5	5	750	375	500	1625
Station D	15	25	10	750	1875	1000	3625
Station E	5	10	5	250	750	500	1500
Demand	50	75	100				
Sales price	90	100	70				
Raw material	40	30	25				
Wage	10	10	5				
Overload	30	30	15				
Product cost	80	70	45				
Product marnin	10	30	25				

Table 2. Product mixed selection by following the product margin creativity.

	Product mix by product margin			
	Product X	Product Y	Product Z	Total
Sales price	90$	100$	70$	
Raw material	40$	30$	25$	
Unit/throughput	0	70$	45$	
Product	0$	75	52	127
Product/throughput		5.250$	2.340$	7.950$
Operational costs				8000$
Factory profit				-410$
D Minutes for each unit	15$	25	10	
D Minutes for each product	0	1875	520	2395

Table 3. Product mixed selection by following throughput according to each constraint time, and TOC based creativity.

	Product mix according to TOC point of view			
	Product X	Product Y	Product Z	Total
Sales price	90$	100$	70$	
Raw material	40$	30$	25$	
Unit/throughput	50$	70$	45$	
Constraints Minutes	15	25	10	
Constraint Min/throughput	3,33$	2,80$	4,5$	
Product	50	26	100	176
Product/throughput	2.500$	1.820$	40500$	8.820$
Operational costs				8.000$
Factory profit				820$
D Minutes for each unit	15	25	10	
D Minutes for each product	750	650	1000	2395

Table 4. An increase in extra pressure on system constraint in product Alpha.

	Each unit capacity needs				Station (Load) (minute)				
	Product X	Product Y	Product Z	Product Alpha	Product X	Product Y	Product Z	Product Alpha	Total Necessities
Station A	20	10	5	0	1000	750	500	0	2250
Station B	0	10	10	0	0	750	1000	0	1750
Station C	15	5	5	0	750	375	500	0	1625
Station D	15	25	10	1650	750	1875	1000	1650	5275
Station E	5	10	5	0	750	750	500	0	1500
Demand	50	75	100	1					
Sales price	90	100	70	6630					
Raw material	40	30	25	30					
Wage	10	10	5	275					
Overload	30	30	15	825					
Product cost	80	70	45	1130					
Product margin	10	30	25	5500					

By product pathology, we take a product or a series of products as target products leading to an optimum solution by TOC creativity if they are influenced.

Product Alpha is expensive and is sold at a price of 6630$ (State 2), which is formed by two units of RM3. For example, its material cost is 30$ and it needs 1650 minutes for processing in station D. It means that extra capacity has been provided for system constraint and it is devoted only to system constraint. The weekly demand for Alpha is one unit. So, as it could be seen in Table (4) the load in station D bottleneck increases fast to 5275 minutes.

Now in this example, how the product selection creativity is executed according to the ratio of throughput per constraint time? Throughput ratio per each minute of constraint is 4.5$ per each minute of constraint for product Z. Supplying the new product Alpha is followed by 4000$ per each minute of constraint. Product X and finally product Y is considered by the ratio of 3.33$ and 2.80$, respectively.

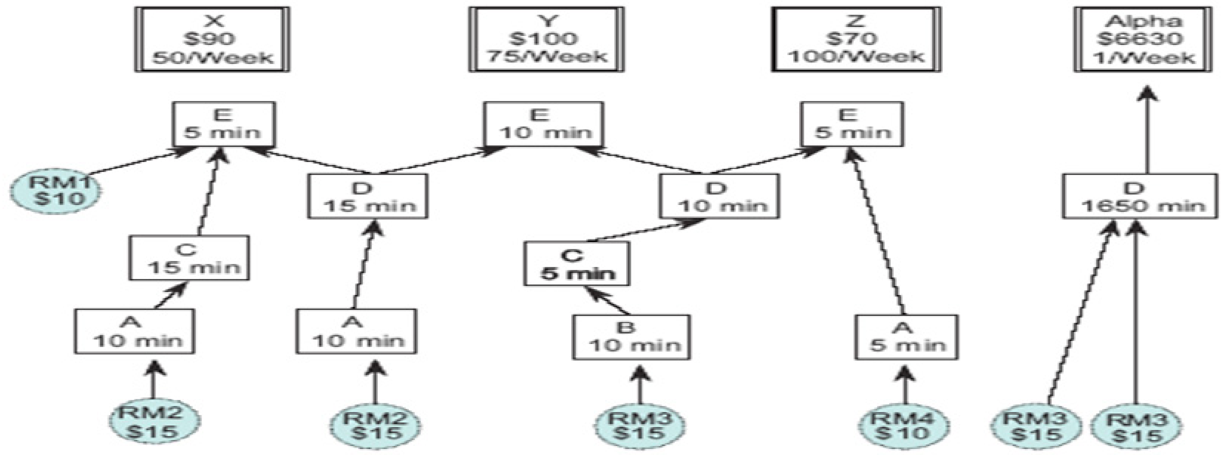

Figure 2. Introducing product Alpha.

Therefore, TOC creativity tells us to start manufacturing product Z with full capacity of total demand. After the demand for product Z is completed, it stays in BN -bottleneck- for 1400 minutes. But, this duration is not for manufacturing the next ratio throughput per each time of constraint. 1650 minutes are needed for manufacturing Alpha. Thus, TOC based innovations results in impractical solution which exceeds the bottleneck available capacity and causes the product Alpha to mutate and manufactures the mix which already introduced product Alpha. What we observe gives a profit equal to 820$. Although the unit with the best throughput (system performance) is never manufactured and instead of classifying only for manufacturing product Alpha and demand for product X, total performance goes toward the profit more than 1100$. Also, it should be noted that to obtain this higher profit, it seems that the operating cost is maintained constant at the level of 8000$, but according to Blackstone (2001), operating costs are based on 1600$ per week and that based on those actions, the table never needs to station B to be activated. Therefore, if the operating cost decreases to 6400$ based on that table, only by selecting the mentioned different product mix thanks to TOC based innovations, the total above profit will increase to 2700$. This behavior is in contrast to current thought in TOC literature and the Reality1 described in introduction. These cases in TOC based innovations failure even with only a constraint source (Table 5).

Table 5. An increase in profit to 1100$ (or to 2700$) if the station B is allowed to be closed.

	Product Alpha: A pathology case for TOC				
	Product X	**Product Y**	**Product Z**	**Product Alpha**	**Total**
Sales price	90$	100$	70$	6.630$	
Raw material	40$	30$	25$	30$	
Unit/throughput	50$	70$	45$	6.600$	
Constraints Minutes	15	25	10	1.650	
Constraint Min/ throughput	3,33$	2,80$	4,50$	4,00$	
Product	50	0	0	1	9.100$
Product/throughput	2.500$	0$	0$	6.600$	8.000$
Operational costs					1.100$
Factory profit					
D Minutes for each unit	15	25	10	1650	
D Minutes for each product	750	0	0	1650	2400

Results and Discussion

State 3(a) shows a very simple group of products (#1, #2, #3, #4) and offers station A and an RM (at price of 100$).

Our program duration and station A capacity is only a workday or eight hours. The price of each unit of final product has a direct influence on the elapsed time in station A and daily demand for one unit of product #1, one unit of product #2, one unit of product #3 and one unit of product #4. As manufacturing those products requires 19 hours, station A is evidently a system constraint and obviously is the only system constraint too. Then, what is the best product mix? Let us find how the product heuristic margin and TOC based creativity are violated.

First, we consider the classic method which allocates the priority to the product which has the highest sales margin (state 3b).

As all products originate from RM1 in this example, we require only select the product with the highest sales price which is product #1. Suppose that product stays six hours in station A and the reminded time to manufacture other products is not enough. So, the total throughput equals to 500$ by this creativity.

Now, we start by selecting the products with the highest ratio for constraint min/throughput utilizing TOC based innovations in state 3(c). In this example, product 2 must be manufactured with the ratio of 110$/h (a ratio higher than 100$, the remaining ratio for all remaining products). It spends five hours in station A, that is not enough for manufacturing the remaining items in station A and results in total throughput equal to 450$. It has been described in Reality 2 in which TOC based creativity to obtain higher profit fails by traditional product margin creativity.

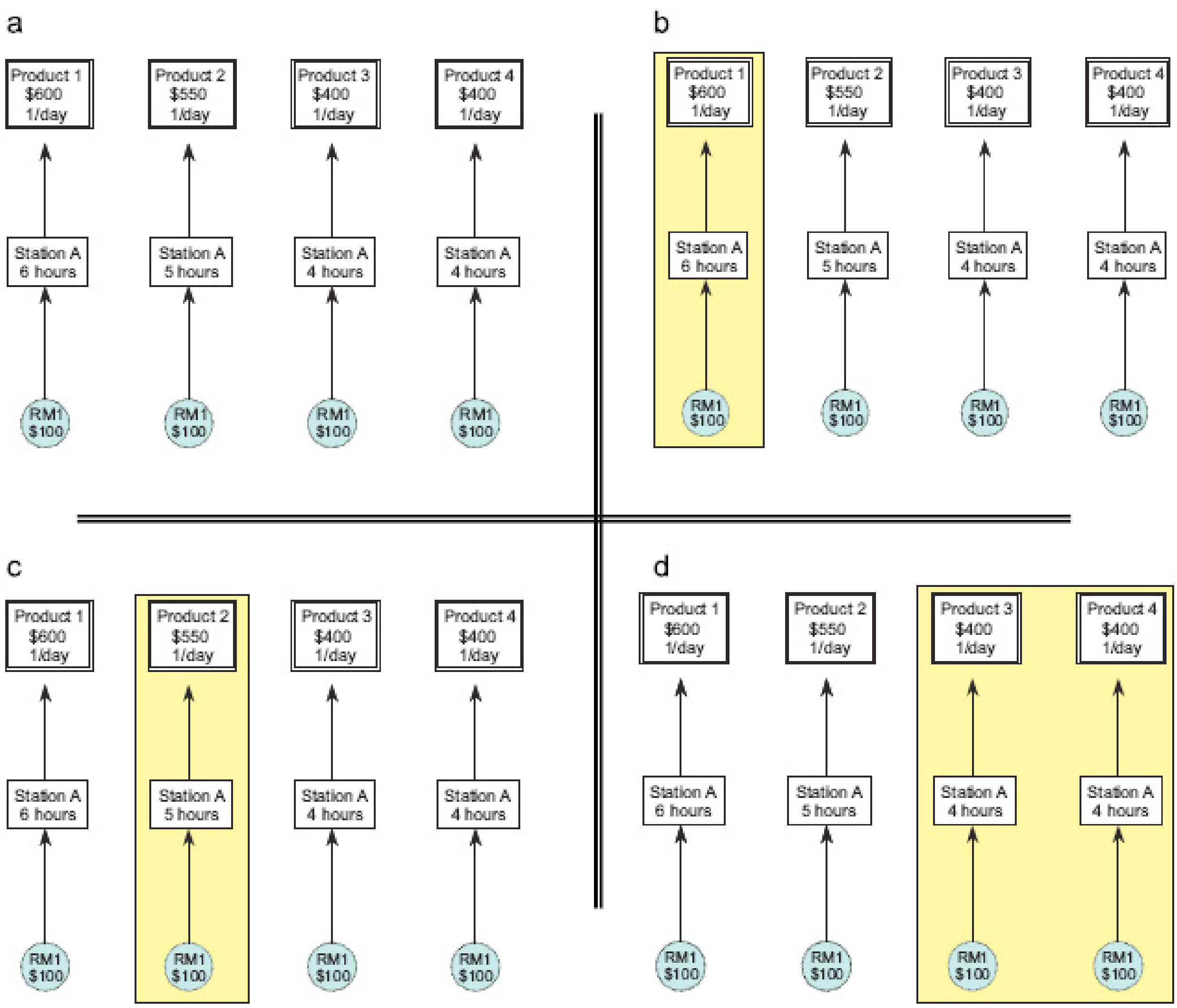

Figure 3.The most simple reason for failure: (a) a simple example with one constraint, (b) the product marginal approach result, (c) TOC based creativity approach results, 450$, (d) optimum solution, both approach violation.

The optimum creativity in this example violate both methods of traditional product margin and TOC based creativity and violates both policies simultaneously and provides total throughput equal to 600$ by manufacturing items having the lowest product margin and throughput ratio (system performance) per each time of constraint. It has been described in Reality 3. These cases violate both traditional and TOC based creativity by optimum product mix including the lowest margin products and throughput ratio (system performance).

The simple example presented in the next part might guide the reader to the following obvious results.

Theorem 1: The selection of product mixture in limited conditions NP-hard.

Proof: Multi-product problem is reduced.

It should be indicated how to determine a polynomial function of timeto help recognize NP-hard in order to prove the issue that product mix selection in limited conditions is an NP-hard (Garey and Johnson, 1979).

Consider the following optimum problem which gives us a pack and a set of items N having value Vi and weight Wi. The multiproduct problem wants us to select a subset of items which their maximum total value is in a pack, while the total weight of those items is incorrect and it is a special (minimum) threshold for T (Garey and Johnson, 1979). That is the famous problem of NP-hard which should be solved. It means there is no recognized method to give a polynomial function of time as a function of N.

It is obvious that no accurate method could be utilized to solve product mix problem and multiproduct problem under TOC.

We take into account a set of products having one bottleneck (station A) and N probable products. Products match with the items put in a pack «or is not put». So, we create an adaptive product for each item. As the previous example indicates, each product includes RM processed in station in station A, the bottleneck. The RM price for each product is 0$. Each product sales price has been given by each item value Vi. The necessary weight (time in minute) is shown by each item Wi weight for each product. Station A capacity (the available time for processing) is equal to the package maximum permitted weight for T.

Mapping is an optimum solution for product mix problem as well as multiproduct problem. Therefore, any accurate algorithm for TOC based could be utilized to solve multiproduct NP-hard problem. Those given proofs,which are the product mix selections in limited conditions, are an NP-hard problem themselves. The above example and its proof is a kind of 0-1 use for multiproduct problem which a binary value is placed or removed.

The situation is more accurate by selecting product mix under a constraint. Although traditionally, the multiproduct problem needs any known item value placed in package, that change in viewpoint does not change the main issue which is NP-hard problem and the effort to achieve the optimum solutions for all cases is impractical.

The reader should note that the result has been conceptually described which the problem adaptation under some constraints is also NP-hard. In order to better understand the reason, suppose that we have a product optimum mix algorithm for the case of some constraints. This algorithm could be used for on constraint as well. For instance, it could be done by adding a new source of constraint and product. In this situation, product value is zero and the new source of constraint is utilized only to manufacture a new product. A solution, which is a direct solution, is to convert the multi-constraint problem to one constraint problem. So, an algorithm for multi-constraint problem will optimally solve an NP-hard problem which is immediately proved that the multi-constraint case is obviously NP-hard as well.

Conclusions

This article clarified by example some cases in which TOC product mix fails even for the case of one bottleneck. The reasons for these continuing failures are not for the method nature but because of the problem nature itself which is called an NP-hard problem. Any algorithm, which solves product mix problem under one or some constraints, it could be utilized to solve NP-hard knapsack too. As an accurate method for selecting a product mix in limited conditions concludes that NP is equal to P (Nature of Problem = Problem), that result has been proved in Reality 4 which there are strong reasons that convinces us it is impossible to simply have optimum and effective creativity to select TOC based product mix. Further, it is clear that Plenter's (1993) results show why researchers are not able to offer a simple optimum creativity for mixing product under some limited sources. As we concluded here, TOC based creativity fails even in the case of one source of constraint.

Therefore, it seems more logical to expect that the best capability which might be achieved for large cases whit high qualitative similarity, are the advanced innovations which have been studied recently (Fredendall and Lee, 1997; Hsu and Chung, 1998; Onwubolu and Mutingi 2001a,b).

Two constraints can be mentioned here as a result. The first constraint is the assumption that we are dealing with some cases which we have complete information about them. This assumption does not reflex the enterprise industry environments in which bottlenecks move quickly and there are huge deviations for each station while these assumptions take part in a huge section of the literature (e.g., Goldratt, 1990a; Fox, 1987).

As another limitation, it is better for the items to be completed in a part of day or week instead of suggesting all items within a period of time. Then, actually TOC based innovations are optimum.

Recognizing TOC philosophy through TOC based product mixed innovations is very hard. This article is never a criticism on TOC. TOC is management philosophy which never requires to be remembered and is completely dependent on few assumptions. The presented results only prove that the approach development could be problematic. It does not oblige that anything about TOC is management philosophy (Mabin and Balderstone, 2003; Mabin and Gibson, 1998; Mabin and Davies, 2003).

Anyway, it gives us an important research issue.

Finally, as TOS is based on removing constraints, how we can utilize its philosophy properly regarding the requested mixes complexity in the case of few products. In spite of that, we do not want product mix to be converted to a bottleneck.

References

Aryanezhad M.B., Komijan A.R., 2004. An improved algorithm for optimising product mix under the Theory of Constraints. International Journal of Production Research. 42(20): 4221–4233.

Balakrishnan J., Cheng C.H., 2000. Theory of Constraints and linear programming: a re-examination. International Journal of Production Research. 38 (6): 1459–1463.

Bhattacharya A., Vasant P., Sarkar B., Mukherjee S.K., 2008. A fully fuzzi ed, intelligent theory-of-constraints product-mix decision. International Journal of Production Research. 46 (3): 789–815.

Blackstone J.H., 2001. Theory of Constraints - a status report. International Journal of Production Research. 39: 1053–1080.

Bluture, 2007. Management Accounting by Emphasizing on Strategy. Translated by Parsaeeian, A. Esmaeeilian & Lalli. Theory of Constraints.

Fox R., 1987. Theory of Constraints. In: NAA Conference Proceedings. pp. 41–52.

Fredendall L.D., Lea B.R., 1997. Improving the product mix heuristic in the Theory of Constraints. International Journal of Production Research. 35: 1535–1544.

Garey M., Johnson D., 1979. Computers and Intractability: A Guide to the Theory of NP-Completeness. W.H. Freeman and Company, San Francisco.

Goldratt E.M., Cox J., 1984. The Goal: A Process of Ongoing Improvement. North River Press, Croton-on-Hudson, NY.

Goldratt E.M., 1990a. Sifting Information Out of the Data Ocean: The Haystack Syndrome. North River Press, Croton-on-Hudson, NY.

Goldratt E.M., 1990b. What is this Thing Called the Theory of Constraints and How Should it be Implemented? North River Press, Croton-on-Hudson, NY.

Goldratt E.M., Fox R.E., 1986. The Race. North River Press, Croton-on- Hudson, NY.

Gupta M.C., Baxendale S.J., Raju P.S., 2002. Integrating ABM/TOC approaches for performance improvement: a framework and application. International Journal of Production Research. 40: 3225–3251.

Hsu T.C., Chung S.H., 1998. The TOC-based algorithm for solving product mix problems. Production Planning and Control. 9: 36–46.

Kee R., Schmidt C., 2000. A comparative analysis of utilizing activity- based costing and the Theory of Constraints for making product-mix decisions. International Journal of Production Economics. 63:1–17.

Lea B.-R., Fredendall L.D., 2002. The impact of management accounting, product structure, product mix algorithm, and planning horizon on manufacturing performance. International Journal of Production Economics. 79:279–299.

Lee T.N., Plenert G., 1993. Optimizing Theory of Constraints when new product alternatives exist. Production and Inventory Management Journal. 34:51–57.

Mabin V., Balderstone S., 2003. The performance of the Theory of Constraints methodology: analysis and discussion of successful TOC applications. International Journal of Operations and Production Management. 23 (6):568–595.

Mabin V., Davies J., 2003. Framework for understanding the complementary nature of TOC frames: insights from the product mix dilemma. International Journal of Production Research. 41 (4): 661–6 80.

Mabin V., Gibson J., 1998. Synergies from spreadsheet LP used with the Theory of Constraints- a case study. Journal of the Operational Research Society. 49: 918–927.

Mishra N., Prakash Tiwari M.K., Shankar R., Chan F.T.S., 2005. Hybrid tabu-simulated annealing based approach to solve multi-constraint product mix decision problem. Expert Systems with Applications. 29 (2):446–454.

Onwubolu G.C., 2001. Tabu search-based algorithm for the TOC product mix decision. International Journal of Production Research. 39: 2065 –2076.

Onwubolu G.C., Mutingi M., 2001a. A genetic algorithm approach to the Theory of Constraints product mix problems. Production Planning and Control. 12: 21–27.

Onwubolu G.C., Mutingi M., 2001b. Optimizing the multiple limited resources product mix problem using genetic algorithms. International Journal of Production Research. 39:1897–1910.

Patterson M.C., 1992. The product mix decision: a comparison of Theory of Constraints and labor-based management accounting. Production and Inventory Management Journal. 33: 80–85.

Plenert G., 1993. Optimizing Theory of Constraints when multiple limited resources exist. European Journal of Operational Research. 70: 126–133.

Rahnemay Roodposhti F., Zarei & Khanmohammadi. Theory of Constraints and its Applications in Management Accounting, Performance Accounting on the Basis of Creativity.

Singh R.K., Prakash Kumar S., Tiwari M.K., 2006. Psycho-clonal based approach to solve a TOC product mix decision problem. The International Journal of Advanced Manufacturing Technology, 29 (11–12):1194–1202.

Wahlers J.L., Cox III J.F., 1994. Competitive factors and performance measurement: applying the Theory of Constraints to meet customer needs. International Journal of Production Economics, 37:229–240.

Wang J.Q., Sun S.D., Si S.B., Yang H.A., 2008. Theory of Constraints product mix optimization based on immune algorithm. International Journal of Production Research (iFirst, 1-23; first published online in 03 March 20 08. DOI Link: /http://dx.doi.org/10.1080/ 0 0207540801975026 S).