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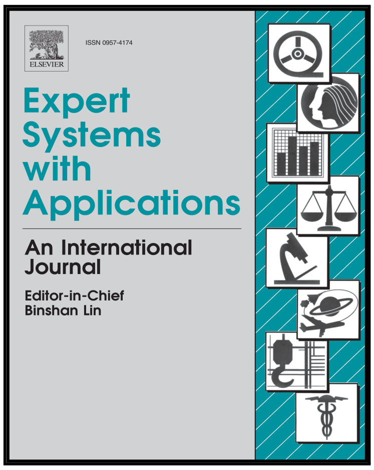

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Highlights

- Analyzes thoroughly Blackstone (2001) and Linhares (2009) product mix selection
- Illustrates that throughput accounting heuristics works still better than alternatives
- Heuristics requires some further analysis on varying product characteristics
- Step-wise changing operating expenses is challenging too, but could also be solved

Throughput Accounting Heuristics Is Still Adequate – Response to Criticism

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Abstract

During the years, number of authors have argued against of possible non-optimality of throughput accounting product mix preference. Lastly, Linhares (2009) criticized throughput accounting heuristics in expanded product mix selection of Blackstone (2001). It is shown in this work that throughput accounting still outperforms any other approach in this referred hypothetical situation, if overall capacity availability of a constraint resource and total throughput per week delivered are being considered (vs. only using throughput per minute of a product). It is critical to expand own point of view to the profit of a system, instead of solely justify decisions on shorter time units, which are not the same with the decision period. However, as we illustrate further, throughput accounting has still its caveats, which arise especially from step-wise increasing operating expenses or from the requirement of integer product mixes. These could be addressed properly by analyzing situation as illustrated in this research work, or alternatively using expert systems concerning customers and operations optimization. Impacts of these actions on short-term profitability are significant.

Keywords: product mix, throughput accounting, optimality, time units

1. Introduction

Within discipline of theory of constraints (TOC), throughput accounting was the third avenue in the development applications, and it was released in the early 1990's (Goldratt, 1990; Watson et al., 2007). Goldratt often referred that cost accounting systems were *"the public enemy number one"* for gaining productivity improvements (Watson et al., 2007), and therefore new accounting approach was needed to be developed. Original two product and four resources as well as demand constrained product mix problem by Goldratt (1990) was introduced, and solved to highlight the path for higher profits. This static example attracted research works in the following decades, and PQ product mix selection was enlarged to incorporate outsourcing, new products and demand increase alternatives (Ruhl, 1997; Atwater& Gagne, 1997;Corbett, 1998; Draman et al., 2002; Hilmola, 2001 & 2004; Ray et al., 2008; Mohanty et al., 2009). Other ever larger product mix problems appeared too in the research works (like Patterson, 1992; Coman& Ronen, 2000; Blackstone, 2001; Nazari-Shirkouhi et al., 2010). In these, typically hypothetical models, throughput accounting was found to perform well, and it usually produced higher profits than conventional accounting heuristics. In double or more constraint situations, its performance was not optimal one, and it has been proposed that throughput accounting should incorporate linear-integer programming to achieve sustainable and optimal results (Plenert, 1993; Balakrishnan, 1999; Mabin, 2001; Aryanezhad & Komijan, 2004; Rajesh, 2014). As in the beginning, throughput accounting was put against full costing systems; this is not any more that much the case. Full cost accounting is nowadays more concerned about long-term performance, and analyzing companies in the light of social, environmental and economic dimensions (Jasinski et al., 2015).

Together with multiple constraints situation, Linhares (2009) argued substantially against throughput accounting heuristics, and used as base hypothetical example of Blackstone (2001). Adding one more product to considerably production resource constrained product mix situation seemed to break-down most of the profit producing ability of throughput accounting. Problem is rooted in capacity vs. one product need for the capacity in the decision time period (e.g. week or day). Although, Linhares (2009) research work is convincing with all propositions and proofs, we intend to illustrate in this research work that its major findings are arising from the poor understanding of management philosophy of theory of constraints and its throughput accounting application. Illustrated situations of poor decision making ability of throughput accounting could and should be solved with throughput accounting, but with proper understanding of system level performance and objective of the system to maximize its results. Bang for the buck heuristics works still well in throughput accounting, but it needs to take into account the availability of production capacity to fulfill the demand. Priority of products by scaling their throughput with production resource cycle time should be checked against the ability to deliver and produce profits. It could be so that highest throughput accounting favored product should be produced as second, and first one priority should be acknowledged to better capacity fit product.

It should be emphasized that this research work is not taking steps to incorporate more uncertainty in the model (Hilmola & Gupta, 2015) or to apply better artificial intelligence algorithms in problem solving (Nazari-Shirkouhi et al., 2010; Rajesh, 2014). Both of these have been used and proposed in recent years to be applied, due to increasing amount of uncertainty in management systems, and options to overcome excessive demand. Artificial intelligence has also been used in accounting context to process demanding amount of qualitative reporting data (Van den Bogaerd & Aerts, 2011). However, this research is partly supporting with described decisions, initiative of using real-time reporting in management accounting (Trigo et al., 2014), where cost and profit control is completed more frequently with modern technology and devices (not in retrospective within longer periods of time). Throughput accounting also gives more attention on purchases, and recently industrial case study of Chompu-inwai et al. (2015) emphasized the importance of improving material efficiency through material flow cost accounting. Purpose of this research work is to return back to the roots and origins of throughput accounting, and illustrate that this accounting approach is not inadequate in product mix decision. However, understandably, some further analysis is needed in product mix decisions, and bang for the buck approach solely and alone can not be used to maximize results.

This manuscript is structured as follows: In the following Section 2, we review the static product mix selection research works. Research environment follows in Section 3. Analysis and solutions of Blackstone (2001) and Linhares (2009) product mix problems are shown in Section 4, where it is illustrated clearly that throughput accounting could overcome described problems stated in Linhares (2009). After this, we shall discuss over the results in Section 5. Research work is concluded in Section 6, where also additional avenues for further research are being proposed.

2. Literature Review: Performance of Heuristics in Product Mix Selection Process

There exist number of different heuristic methods to solve product mix decision. One of the oldest is the cost accounting based decision. Logic in here proceeds in a way that we have to trace all the costs, which product accrues and make the evaluation based on absolute and/or relative profit of the product. Some of the product costs are easy to trace to products, like raw materials and purchased components as well as possibly needed transportation services (e.g. to acquire raw materials and/or distribution of products). However, after this all certain ends and overhead, indirect labour as well as indirect purchases are allocated with some sort of drivers and/or departmental/functional rates (Fisher &Krumwiede, 2012). This leads in product profitability examination to full costing result from where decision maker just selects most lucrative product to produce. Selection could be made again in absolute or relative basis. This is cost accounting heuristics based approach.

Another alternative in product mix selection is to use throughput accounting principles, where only direct costs such as raw materials and transportation costs are devoted to products. Rest of the costs are considered as operating expenses, which are seen as fixed in the short-term (Fisher & Krumwiede, 2012 refer similar approach as 'throughput costing'). Best products to be produced are typically found by scaling throughput of particular product (sales price minus direct costs) to the used time at constraint resource. Product priority list shall contain in descending order all products based on their throughput abilities.

In original example (manufacturing of P and Q) it was found that cost accounting produced $300 of deficit per week as throughput accounting produced $300 of profit (Goldratt, 1990; Hilmola & Gupta, 2015). Research works in previous decades have found similar differences, and in most of the cases logic and heuristics of throughput accounting was more profitable for a manufacturer. Early study of Patterson (1992) showed remarkable difference in profitability of these two approaches, favoring that of throughput accounting (weekly loss was $818 with cost accounting, while profit using throughput accounting was $8872). Hilmola (2004) enlarged original P and Q product mix problem to consist new additional products of R and S; this resulted on further losses within traditional cost accounting approach (-$550), while throughput accounting prospered further ($1249.98).

Blackstone (2001) found in three product example (same as analyzed further in this research, which was enlarged by Linhares, 2009) that conventional cost accounting produced weekly deficit of $410 as throughput accounting resulted to $820 of profit. Outsourcing study of Mohanty et al. (2009) found difference in real-life case study out of Indian manufacturer that standard cost accounting produced profit of $745.25 in work shift, while throughput accounting achieved level of $760.52. Nazari-Shirkouhi et al. (2010) found similar difference in hypothetical production outsourcing example (same as reported in Coman & Ronen, 2000), where standard cost accounting produced profits of $17,200, and throughput accounting in turn $18,428.

Even if evidence supports throughput accounting superiority over standard cost accounting and it is well documented, this alternative approach is not the final answer to the product mix problems. As told earlier, when multiple simultaneously holding constraints exist, then throughput accounting is not necessarily producing best results, but different optimization will (Plenert, 1993; Balakrishnan, 1999; Mabin, 2001; Aryanezhad & Komijan, 2004; Rajesh, 2014). Also adding uncertainty to the product mix models has brought findings that throughput accounting needs to be incorporated with balanced scorecard type of measurement (to assure correct continuous improvement; Gupta, 2012), while Hilmola & Gupta (2015) showed that uncertainty in original P and Q model will erode profits easily away from throughput accounting product mix too. Great uncertainty in production cycle times of original P and Q model (Hilmola & Lättilä, 2008) could also possibly favor emphasizing product Q in product mix selection (under certain premises).

3. Research Environment

In original product mix selection situation of Blackstone (2001) there were three products, called X, Y and Z. These had sales prices of $90, $100 and $70 respectively. All of the sold products needed some raw materials, where product X had need for in total $40 (RM1 and two RM2), while product Y in turn $30 (RM2 and RM3). Lastly, product Z needed $25 for raw materials (RM3 and RM4). Manufacturing of these three products also consumed production resources A, B, C, D and E. Figure 1 illustrates situation in details. In original product mix situation manufacturing company had operating expenses of $8000 per week. These were considered as fixed and included all other costs (indirect and direct labour, indirect purchases, rents, depreciation of machinery, energy etc.) than truly variable ones (raw materials). Even if Linhares (2009) argues that Blackstone (2001) example has some flexibility regarding operating expenses (these are dependent do we use all resources A, B, C, D and E – having cost of $1600 per resource, if used during the week). However, we could not find such information out of Blackstone (2001) original example. Blackstone (2001) refers that labour cost in each resource is $400 per station per week (with five resources this makes $2000 per week), which originates from $10 per hour labour cost. However, rest of operating expenses are just said to be three times that of direct labour.

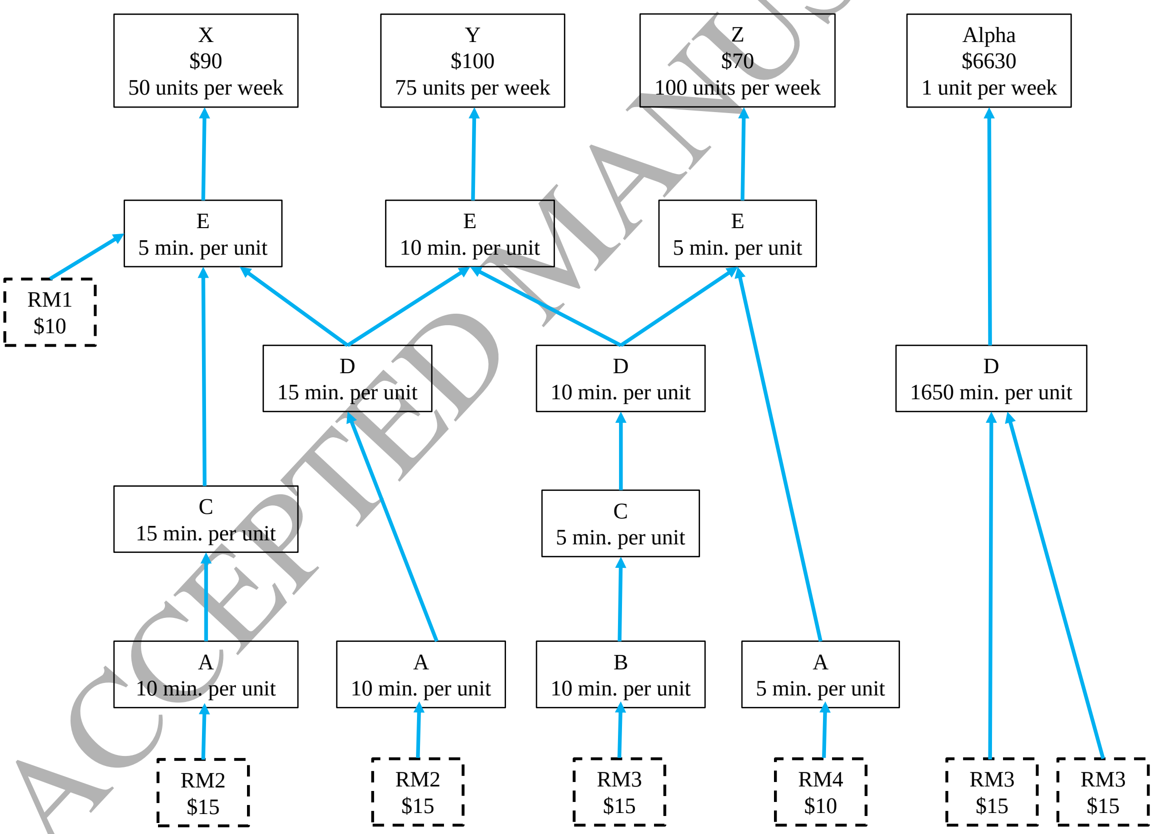

Figure 1. Four products with demand and prices, five resources, production cycle times and raw materials used in expanded product mix problem of Linhares (2009) from original hypothetical example of Blackstone (2001).

Original three product problem was expanded by Linhares (2009) to take into account one new product, called Alpha. This paper tried to illustrate mostly that throughput accounting would not work in product mix selection that well. Product Alpha was having abnormal characteristics: substantially higher sales price, low demand per week, requirement for significant amount of resource D (nothing else) and very low amount of raw material needed (as thinking about sales price). Such kind of product could always exist, but it would be very rare situation in real-life. For example, typically competition in markets is such rigid one that raw materials alone can not be so low as thinking about share from sales price (0.5 %). Raw materials and purchases range in reality from 30-70 % out of product sales price. However, Alpha could still exist, and it is good to have product alternative, which is testing the robustness of throughput accounting. Based on our opinion this testing was not completed correctly in Linhares (2009) research work, and therefore this additional research was required.

Do note that in original (Blackstone, 2001) and expanded (Linhares, 2009) product mix selection examples it was assumed that production resources have each one availability for 2400 minutes per week. So, expanding product alternatives to be supplied for market demand will not change the amount of resources used for production. Only product options will increase for a manufacturer.

4. Showing How Throughput Accounting Really Works

Original Hypothetical Product Mix Problem of Blackstone (2001)

In the original product mix selection situation, Blackstone (2001) evaluated two different approaches: one of traditional cost accounting, and second one of theory of constraints / throughput accounting. Preference in latter was based on profit generation ability of three different products as from sales price was deducted truly variable costs (raw materials) and this was divided by the constraint resource cycle time. Do note that not all demand of X, Y and Z is being able to be served with current resources. Actually, it is so that resource D limits supply as manufacturer has availability for 2400 minutes per week, but demand is for

3625 minutes (if all demand is supplied for markets). Therefore, product based profitability in throughput accounting needs to be calculated through resource D. Most profitable product is then product Z, producing $4.5 per min. ($70 minus $25 divided by 10 min. per unit), and it is followed by product X with $3.33 per minute ($90 minus $40 divided by 15 min. per unit). Least profitable product is Y, contributing $2.8 per minute ($100 minus $30 divided by 25 min. per unit). So, if capacity needs to be allocated for profitability, then as first company should supply and produce product Z, and as second concentrate on product X. If time is left at constraint resource, lastly could be produced product Y.

Table 1. Three different products with demand and resource constraints (manufacturer has 8000 USD fixed operating expenses per week): suggested solution of Blackstone (2001), which is also optimal in linear-integer programming.

Item	X	Y	Z
Throughput margin (absolute)	50	70	45
Quantity	50	26	100
Throughput	2500	1820	4500

Total throughput	Operating Expenses	Profit/Loss
8820	8000	820

	X	Y	Z	Used	Available	Difference
Resource A	1000	260	500	1760	2400	640
Resource B	0	260	1000	1260	2400	1140
Resource C	750	130	500	1380	2400	1020
Resource D	750	650	1000	2400	2400	**0**
Resource E	250	260	500	1010	2400	1390

	X	Y	Z
Demand constraint	50	75	100

As illustrated in Table 1, similarly Blackstone (2001) concluded that throughput accounting approach will yield weekly profits, worth of $820. In this situation, all the demand of product Z and X is being produced, while 26 units of product Y are supplied. Resources are used so, that resource D is used in full, while all the others remaining resources do have slack.

In Blackstone (2001) article, it was also analyzed the end result of using conventional cost accounting, where labour costs and overhead was distributed to the products based on resource use times. Best absolute product margin was in product Y, followed by product Z, and least profitable was product X. So, this traditional approach resulted to produce all the demand of Y, and 52 units of product Z. Financial outcome of this was depressing as weekly losses amounted $410. So, throughput accounting was truly making difference in here. In retrospective it could be stated that Table 1 product mix is also optimal one, highest possible with these constraints.

Expansion of Linhares (2009) and Originally Suggested Solution

As earlier concluded, Linhares (2009) expanded Blackstone (2001) situation with additional product Alpha. This new product will only increase the demand for resource D as it is now in full product supply in total 5275 minutes (vs. availability of 2400 min.). The selection of right product mix becomes then even more critical. As a solution, Linhares (2009) proposes favoring product Alpha, and producing with remaining capacity product X. This will yield to weekly profit of $1100 as illustrated in Table 2.

Table 2. Four different products with demand and resource constraints (manufacturer has 8000 USD fixed operating expenses per week): suggested solution of Linhares (2009).

Item	X	Y	Z	Alpha
Throughput margin (absolute)	50	70	45	6600
Quantity	50	0	0	1
Throughput	2500	0	0	6600

Total throughput	Operating Expenses	Profit/Loss
9100	8000	1100

					Used	Available	Difference
Resource A	1000	0	0	0	1000	2400	1400
Resource B	0	0	0	0	0	2400	2400
Resource C	750	0	0	0	750	2400	1650
Resource D	750	0	0	1650	2400	2400	**0**
Resource E	250	0	0	0	250	2400	2150

	X	Y	Z	Alpha
Demand constraint	50	75	100	1

Table 3. Four different products with demand and resource constraints (weekly operating expense depends from used manufacturing resources, where 1600 USD expense is activated, if resource is being used): suggested solution of Linhares (2009).

Item	X	Y	Z	Alpha
Throughput margin (absolute)	50	70	45	6600
Quantity	50	0	0	1
Throughput	2500	0	0	6600

Total throughput	Operating Expenses	Profit/Loss
9100	6400	2700

					Used	Available	Difference
Resource A	1000	0	0	0	1000	2400	1400
Resource B	0	0	0	0	0	2400	2400
Resource C	750	0	0	0	750	2400	1650
Resource D	750	0	0	1650	2400	2400	**0**
Resource E	250	0	0	0	250	2400	2150

	X	Y	Z	Alpha
Demand constraint	50	75	100	1

Linhares (2009) does not reveal from where result of favoring two above mentioned products is arising from. However, in the article it is referred that such product mix is extremely profitable in situation, where operating expenses are based on the resource item usage ($1600 per resource per week, if used). With respect of selected product mix, resource B remains to be unused during the week, so operating expenses ought to decrease to $6400 per week. This would mean that weekly profits would increase substantially to $2700 (see Table 3). Illustrated product mix within step-wise changing operating expenses is anyway such that it erodes a little bit the superiority of throughput accounting as second and third profitable products together are able to produce such high and increased profits. However, with step-wise changing operating expenses product mix of Table 3 is not the highest possible profit to be gained out of this hypothetical situation. We shall revisit this later on in this research work.

Expansion of Linhares (2009) and Throughput Accounting Solution

From the point of view of throughput accounting, new and low volume product of Alpha is very interesting. It produces $4 per minute in constraint resource ($6630 minus $30 divided by 1650 min. per unit). This is higher than product X ($3.33 per min.), but lower than product Z ($4.5 per min.). Therefore, it is logical to conclude and propose that manufacturer should produce first all demand of product Z, and right after continue to satisfy demand of Alpha, and thereafter products X and Y (if capacity is left). This is actually referred in Linhares (2009) publication as throughput accounting solution.

However, difficulties arise from totally different product routing and production phase time characteristics of the products. If product Z is produced in full, only 0.848 of product Alpha is being able to be produced (as we do have capacity constraint in resource D). If supply lead time for product Alpha is not less than week, this could still be feasible solution (delivery in Monday, if product Alpha is produced in sequence so that it follows product Z). Even if Linhares (2009) neglects this solution, it is actually still feasible in certain environments and situations. It basically depends on assumptions that are we able to supply in longer lead times and produce within week time frame less than integer amounts. If partial production of product Alpha is allowed, then throughput accounting yields extremely nice profit, $2100 per week. This solution is shown in Table 4, and it is $1000 per week more profits than what was in Table 2 proposal. So, throughput accounting still works, if environment allows its allocation.

Table 4. Four different products with demand and resource constraints (manufacturer has 8000 USD fixed operating expenses per week): throughput accounting solution, allowing non-integer solution.

Item	X	Y	Z	Alpha
Throughput margin (absolute)	50	70	45	6600
Quantity	0	0	100	0.848
Throughput	0	0	4500	5600

Total throughput	Operating Expenses	Profit/Loss
10100	8000	2100

	X	Y	Z	Alpha	Used	Available	Difference
Resource A	0	0	500	0	500	2400	1900
Resource B	0	0	1000	0	1000	2400	1400
Resource C	0	0	500	0	500	2400	1900
Resource D	0	0	1000	1400	2400	2400	**0**
Resource E	0	0	500	0	500	2400	1900

	X	Y	Z	Alpha
Demand constraint	50	75	100	1

Table 5. Four different products with demand and resource constraints (manufacturer has 8000 USD fixed operating expenses per week): throughput accounting solution, which is also optimized solution in linear-integer programming.

Item	X	Y	Z	Alpha
Throughput margin (absolute)	50	70	45	6600
Quantity	0	0	75	1
Throughput	0	0	3375	6600

Total throughput	Operating Expenses	Profit/Loss
9975	8000	1975

	X	Y	Z	Alpha	Used	Available	Difference
Resource A	0	0	375	0	375	2400	2025
Resource B	0	0	750	0	750	2400	1650
Resource C	0	0	375	0	375	2400	2025
Resource D	0	0	750	1650	2400	2400	**0**
Resource E	0	0	375	0	375	2400	2025

	X	Y	Z	Alpha
Demand constraint	50	75	100	1

If integer solution is demanded, then it is not fair to say that throughput accounting fails and is non-optimal. Whole issue is arising from the extremely different characteristics of produced products. Alpha is simply taking so much from production time of resource D that in some product mix situations it can not be produced as integer amounts. In here situation is such. Therefore, it would be reasonable to assume that decision maker will change the sequence of preferred products. Reason is simple, producing product Z alone will not lead to profits and returning to original solution of Blackstone (2001) will yield $820 per week (instead of $1100 per week in Linhares, 2009). However, it would be reasonable to assume that decision maker shall stick with recommendation of throughput accounting, favoring products Z and Alpha. However, as it is impossible to firstly to prefer product Z and thereafter product Alpha, throughput accounting solution would change the sequence. This could be justified with the purpose of the system trying to produce as much as profit as it can, as objective of the company is for profit, and increasing amounts of it. All the other solutions would be moving away from this goal. Therefore, in integer solution of throughput accounting it would be reasonable to assume that manufacturer produces one unit of Alpha first, and with remaining capacity, it will produce product Z, in total 75 units. This will yield weekly profit of $1975, which is $875 more than what was the case at Linhares (2009) solution. This is also optimal in linear-integer programming.

Possibility of Step-Wise Changing Operating Expenses, where Throughput Accounting Does Not Traditionally Perform

It is of course so that in the case of step-wise changing operating expenses solution of throughput accounting in Table 5 is not as good as Linhares (2009) suggested, and what was presented in Table 3. Even if Linhares (2009) emphasized that integer production amount solution is the Achilles heel of throughput accounting, but it is not necessarily so. From these situations throughput accounting still performs and survives well, as long as decision maker keeps in mind to aim highest possible product throughput based profit generation through constraint resource, however, with respect of system profits. Latter should be the driver of the decision.

As said, in step-wise changing operating costs throughput accounting is not performing well. Rule of thumb and guidance for product priority is based on assumption of fixed operating expenses, and if this assumption is violated, it is difficult to produce highest possible profit in hypothetical situations with plain throughput accounting. However, throughput accounting can be part of the solution (or aid) as is illustrated in the following.

Table 6. Four different products with demand and resource constraints (weekly operating expense depends from used manufacturing resources, where 1600 USD expense is activated, if resource is being used): optimized solution in linear-integer programming, which is aided by throughput accounting approach.

Item	X	Y	Z	Alpha
Throughput margin (absolute)	50	70	45	6600
Quantity	0	0	0	1
Throughput	0	0	0	6600

Total throughput	Operating Expenses	Profit/Loss
6600	1600	5000

	X	Y	Z	Alpha	Used	Available	Difference
Resource A	0	0	0	0	0	2400	2400
Resource B	0	0	0	0	0	2400	2400
Resource C	0	0	0	0	0	2400	2400
Resource D	0	0	0	1650	1650	2400	**750**
Resource E	0	0	0	0	0	2400	2400

	X	Y	Z	Alpha
Demand constraint	50	75	100	1

If step-wise changing operating expenses are tried with optimization software, it will result as shown in Table 6. Interestingly, it would be feasible only to produce second highest throughput product Alpha and keep resources A, B, C and E closed. This will result on weekly profits of $5000. In one way, this is related to throughput accounting solution, but eventually solution is dependent on special characteristics of product Alpha. Therefore, we may conclude that throughput accounting is worthwhile to check (or at least to try) in step-wise changing operating expenses. Solution could be found from products having very uneven use of resources, having one of the best throughput per minute from all products available, and producing alone enough absolute throughput per period in concern (in here, one week). It is also vital that the use of resources in manufacturing process is such that resources do not compete from the position of being a constraint (unbalanced rather than balanced; not like in simulation study of Golmohammadi, 2015) – there is just one clear constraint resource, like in analyzed hypothetical example (resource D). In this hypothetical situation decision maker would only needed to check the weekly result of producing product Z and Alpha alone, and thereafter make interpretation out of the analysis. Analysis is extremely profitable as Table 6 solution shall produce $2300 per week more than Linhares (2009) solution in Table 3.

5. Discussion

Based on above analysis it can be found that throughput accounting will provide appropriate solution in different situations comparing to classical cost accounting method. Linhares (2009) neglected the possibilities of product mix of Alpha and Z, and choose the product mix of Alpha and X. Why he did so, was not revealed in original paper. His conclusion is not logical without the consideration of the product mix of Alpha and Z. The product mix and its operating profit of different solutions can be summarized as follows in Table 7.

Table 7. Comparison of operating profit of product mix problem of Linhares (2009).

Item	X	Y	Z	Alpha	Total Throughput	Operating Expenses	Profit
Linhares (2009) suggested solution	50	0	0	1	9100	8000	1100
TOC non-integer solution	0	0	100	0.848	10100	8000	2100
TOC integer solution	0	0	75	1	9975	8000	1975
Linhares (2009) suggested solution with variable weekly operating expense	50	0	0	1	9100	6400	2700
Linear-integer programming solution with variable weekly operating expense	0	0	0	1	6600	1600	5000

From Table 7 it can be found that operating profit of TOC solution is larger than non TOC solution that Linhares (2009) suggested in product mix problem. If the weekly operating expense is fixed, TOC integer solution will yield weekly profit of $1975, which is $875 more than what was the case at Linhares (2009) solution. TOC non-integer solution will yield weekly profit of $2100, which is $1000 more than what was the case at Linhares (2009) solution. If the weekly operating expense is variable, linear-integer programming (also partially throughput accounting as illustrated in earlier section) solution will yield weekly profit of $5000, which is $2300 more than what was the case at Linhares (2009) solution with variable weekly operating expense. Throughput accounting can often provide optimal solution in the situations of fixed operating expense and with some useful analysis on the finding through iteration optimal solution in variable weekly operating expense.

In the discussion part of Linhares (2009), it is unfair to say that throughput accounting fails and is non-optimal in the extremely simple case. In the case there are a set of products {#1, #2, #3, and #4}, a single work station A, and a single RM (worth of $100 for each product). The planning period, and the capacity of station A, is a single workday, or 8h. The selling price of each final product is a direct function of the time spent on station A, and the demand for the day is one of product #1 (sales price $600; 6 hours resource use), one of product #2 ($550; 5 hours), one of product #3 ($400; 4 hours), and one of product #4 ($400; 4 hours). Since the production of these items would require 19 h, station A is clearly a system constraint and is obviously the only one. Now what is the best product mix? Linhares (2009) concluded that the classic cost accounting product mix is to produce one unit product #1 and the total throughput would equal $500 under this heuristic. TOC integer solution will yield daily total throughput of $450 with one unit of product #2. The optimum heuristic for this case is to produce one unit product #3 and one unit product #4. And the total throughput would equal $600 under this heuristic. Linhares reckoned the above result is the best. This violates both the traditional product margin heuristic and the TOC heuristic and to produce the items with the lowest product margin and the lowest ratio of throughput per constraint time. In this case, the remaining hours would not be sufficient time to produce any of the remaining demanded items and were neglected in the classical heuristic and TOC heuristic.

If non-integer solution is permitted, 1.33 of product #1 will be produced daily with classical cost accounting heuristics. Classical non-integer solution will then yield daily total throughput of $500×1.33=$666.67. By using the TOC-derived heuristic we would start by selecting the products with the highest relation of throughput/constraint time, which turns out in this case to be product #2, with 90$/h. In one day time, 1.6 of product #2 will be produced. TOC non-integer solution will yield daily total throughput of $450×1.6=$720. TOC-derived heuristic does obtain a higher profit than the traditional product margin heuristic. If the optimum heuristic for this case were to produce one unit product #3 and one unit product #4, the total throughput would equal $600. Comparing to the results of classical cost accounting solution or TOC solution, the result of Linhares optimal solution is the lowest. Here TOC non-integer solution provides the highest total throughput and is optimal solution (and <u>is</u> integer solution in weekly basis, where week consists five working days).

If integer solution is demanded, then it is not fair to say that throughput accounting fails and is non-optimal. The issue is arising from the tight constraint time period that only consists of one single working day. If we extend time cycle longer to such as a week, TOC solution will provide the highest total throughput in Linhares (2009) case. This provided solution is also optimal in linear-integer programming. Above analysis shows the results, that throughput accounting heuristics is still adequate in many situations. However, decision makers should ask from themselves, what is the supply lead time window and requirement of operations with respect of customers – if it is not that critical to supply a little bit later, then non-integer solution is useful and provides best financial results. In a case, that product mix solution needs to be integer one, then it is critical to think about the overall profitability of the system. It might be so that the sequence of most profitable products should be changed in prioritizing (situation shown in Table 5). Most important issue in integer situations seems to be using constraint capacity in the best possible way – like in earlier analyzed one resource and product #1 to #4 case illustrates. Here integer solution leads to the preference of least profitable (in both throughput and conventional accounting sense) products, however, this is due to the reason that delivered and produced throughput of these two products together is better than what is the situation with product #2 (as three hours are left unused).

6. Conclusions

It is roughly quarter of century from the introduction of throughput accounting, and its profit maximization approach. This new accounting approach started from hypothetical PQ example, and still today, research discusses through hypothetical problems, like in this manuscript. Implementations of throughput accounting of course exist, but its fundamental theory development is dependent on hypothetical problems. In this research work, we concentrated on three product problem introduced by Blackstone (2001), which was enlarged with additional product by Linhares (2009). This research illustrated clearly that throughput accounting is still adequate approach for profit maximization, in situation, where only one major production constraint exist. Combinatorial complexity of numerous products and their varying characteristics could be dealt, if additional step is added on throughput accounting product mix selection process. It is typically assumed that throughput accounting requires only capacity check for constraints with maximum demand, and thereafter scaling and selection the most profitable products based on bang for the buck evaluation method. As illustrated in this research work, a posteriori analysis is needed to check, how feasible selected sequence is. As illustrated in this research work, sometimes situations (like that introduced by Linhares, 2009) are such that one product is having enormous capacity need from production of one unit that it should be prioritized instead of highest throughput product. However, this does not change the core of throughput accounting that much – priority list of products is still on use, but it should be modified due to this (best products are still the ones shown by the bang for the buck). System profit, however, is the objective in these product priority modifications. In some situations (should be rather rare), like referred in discussion section (with products #1 to #4), tight daily capacity with respect of one unit production capacity need of different products could lead to favor lower profitability products as aim is to have daily integer product mix. This again is done due to system profit objective. As illustrated, if non-integer solutions are allowed for daily solutions in this situation (with products #1 to #4), throughput accounting was superior against the others (interestingly non-integer daily decision leads to integer solution in weekly basis with throughput accounting approach).

As an additional challenge of throughput accounting is the flexibility (change) of cost structure with the volume and use of resources. As given in original assumptions, it was assumed that cost structure does not change in the short-term at all, and it is fixed. In this research work, we tried to find optimal situation with throughput accounting in such circumstances, where cost structure shows flexibility, and found that highest throughput products are candidates for optimizing profits in these cases. Therefore, capacity does not need to be utilized even for full in all resources (even could be below within system constraint), if cost structure is flexible enough. In this situation, operating expenses are the constraint for profits, not production capacity.

As a further research, it would be vital for the sake of theory development to collect all different hypothetical models together and evaluate the appropriateness of throughput accounting and optimization algorithms as a whole. This was already in part done by Rajesh (2014), where multi-constraint situation was analyzed through number of previous models. Approach and analysis should be enlarged also to single constrained situations, where throughput accounting is said to perform well or poor. As illustrated in this research work, often is the case that throughput accounting performs extremely well, if it is understood properly. Theory in here is more than just a mechanistic rule of thumb applied without system performance check in product mix selection.

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