THE THEORY OF CONSTRAINTS: A COMPARATIVE ASSESSMENT

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ABSTRACT

The worldwide economic reorganisation of the last decade has regularly been accompanied by appeals to concepts of lean manufacturing and flexible systems. These generally imply a scaling of productive and operating capacity to match demand and current throughput levels. The issue of how to manage scarce capacity has risen in priority both because of a constant search for greater efficiency and because of imbalances between the supply and demand of many resources. Multiple constraints have emerged throughout the Irish economy for individual firms, and for entire sectors. Firms in the internationally traded sector operate within the constraints of globalised lean production models. Those in the non-traded sectors face novel problems related to the shortage of staff and other resources, where slack and under-utilisation might previously have presented the primary resource issues.

A question arises as to contribution of management accounting in managing such problems, given that issues related to capacity have long been considered in accounting. Despite this there is a relative lack of advanced quantitative techniques in daily use as recommended in the literature. The optimisation approach of linear programming allows for the solution of complex problems involving multiple capacity constraints. While the principle has been known, and taught on accounting courses for a long period, there is little evidence of widespread use in accounting or broader managerial practice.

In "The Goal" Eli Goldratt reinvigorated traditional optimisation insights by presenting them in the repackaged form of the Theory of Constraints (Goldratt and Cox (1993)). This management best seller took the form of a thriller following the struggle of plant manager with 90 days to save his loss making operation from shutdown. In it Goldratt and Cox attack cost accounting as the "enemy number one of productivity" and instead called for a holistic process of ongoing improvement integrating techniques such as MRP, Just in Time and Statistical Process Control.

This paper examines in detail the relative utility of the Theory of Constraints compared to traditional management accounting approaches to resource utilisation in aiding decisionmaking. It also considers the propagation and evolution of the Theory of Constraints and critically examines the response it has generated in the accounting and management literature. The continuing survival of cost accounting in the face of frequent assaults similar to Goldratt's may in part be due to the ability of the discipline to adapt its practices to integrate the mandated improvements into practice and educational curricula. One example is the Theory of Constraints itself (e.g. Horngren et al (1999) and Morse & Zimmerman (1997)). The paper reflects on the process by which new ideas are assimilated into the conventional management wisdom based on this example.

KEYWORDS

Capacity Management, Theory of Constraints, Management Accounting.

INTRODUCTION

The worldwide economic reorganisation of the last decade has regularly been accompanied by appeals to concepts of lean manufacturing and flexible systems. These generally imply a scaling of productive and operating capacity to match demand and current throughput levels. The recent Irish economic boom also highlighted the importance of consideration of capacity management issues. These have arisen both because of constant appeals to greater efficiency, and because of imbalances between the supply and demand of many input resources. The problem of capacity management arises both in a macroeconomic and local, or firm level context. A question arises as to contribution of management accounting in managing such problems. Although issues related to capacity have long been considered in accounting there is a relative lack of advanced quantitative techniques in daily use as recommended in the literature.

THE THEORY OF CONSTRAINTS

In "The Goal" Eli Goldratt reinvigorated traditional optimisation insights by presenting them in a repackaged form (Goldratt and Cox (1993)). This management best seller took the form of a thriller following the struggle of plant manager with 90 days to save his loss making operation from shutdown. In it Goldratt and Cox attack cost accounting as the "enemy number one of productivity" and instead called for a holistic process of ongoing improvement integrating techniques such as MRP, Just in Time and Statistical Process Control. The continuing survival of cost accounting in the face of frequent assaults of this type may in part be due to the ability of the discipline to adapt its practices to integrate the mandated improvements into practice and educational curricula. One example is the Theory of Constraints itself (e.g. Horngren, Bhimani et al (1999) and Morse & Zimmerman (1997)).

The theory of constraints (TOC) describes methods to maximise operating profit by identifying bottleneck operations, recognising that the bottleneck resource determines the throughput contribution of the plant as a whole. The bottleneck may be found by identifying operations with large backlogs of stock waiting to be worked on. A summary of the development of the theory is included in Jones & Dugdale (1998).

The manager must then ensure the bottleneck resource is always kept busy and other resources are subordinated to the bottleneck in scheduling, and in prioritising investment.

The Theory of Constraints is built on three central measurements:

1. Throughput contribution = sales revenue - direct materials cost.
2. Investments (stock) = Inventory (i.e. Raw materials, WiP, Finished Goods (materials content only)) + R & D costs + Buildings and Equipment.
3. Operating costs = includes operating costs other than direct materials, includes labour costs and overheads including depreciation. These are all implicitly assumed to be fixed. This assumption leads many commentators to the conclusion that TOC measures have a short run time horizon.

TOC aims to maximise throughput contribution while decreasing investments and operating costs. This is done by following a series of focusing steps to manage bottleneck resources.

Five Focusing Steps

STEP 1: Recognise that the throughput contribution of the entire plant is limited by the bottleneck resource.

STEP 2: Identify the bottleneck resource, generally by seeing where there is a build-up of stock waiting to be worked on.

STEP 3: Keep the bottleneck operation busy all the time, and subordinate all other operations to it. The needs of the bottleneck resource drive the production schedule of other resources. It sets the pace for other machines or operations. Producing more elsewhere only leads to excess stock without increasing throughput contribution. TOC demands the elimination of most Work in Process inventory. TOC does however advocate the maintenance of a buffer stock before the bottleneck machine to ensure that it is never unnecessarily idle.

STEP 4: Elevate the systems bottlenecks by increasing system capacity. This is done if the increase in throughput contribution exceeds the incremental cost of improvement.

STEP 5: If in the previous steps a constraint has been broken, return to step 1.

DRUM, BUFFER, ROPE

Goldratt distills the lesson of TOC into the triad of Drum, Buffer and Rope. The resulting production systems allow the rhythm of production to follow the beat of the bottleneck machines

(Drum), which have a cushion of safety stock before them (Buffer) as they alternately pull or choke the release of materials to follow customer orders (Rope).

THE THEORY OF CONSTRAINTS AND ACCOUNTING

Goldratt & Cox's (1993) reasons for identifying cost accounting as the "enemy number one of productivity" are illustrated in the story of "The Goal". The hero, Alex, finds that as production was cut on non bottleneck machines, to follow the beat of the "Drum", this was reported as falling capacity utilisation rates to his Divisional head office. Newer accounting measures such as Activity Based Costing (ABC) may reinforce the weaknesses of traditional accounting practices based on absorption costing, by providing an incentive for higher output at each activity and fewer setups (and hence longer production runs), leading to excessive output at non-bottleneck resources. In general the TOC emphasises the provision of information for decisionmaking, rather than for management control or product costing.

Proponents of TOC also point out that traditional accounting measures penalise the improved plant efficiency from TOC resulting from the release to the Profit and Loss account of the previous surplus Work in Process output from non-bottleneck machines (previously carried forward as an asset on the Balance Sheet).

It should be noted however that this effect is confined to the amount of allocated overhead inventorised in WiP, and furthermore it is a "one off" transitory effect on the first implementation of TOC, which only occurs while the quantity of WiP is falling.

What is interesting is the extent to which the criticisms of accounting voiced in the Theory of Constraints are accepted, at least in part in accounting commentaries or analyses of the TOC. For example Jones & Dugdale (1998) concentrate on the influence of TOC and the question of whether it represents a paradigm shift. They therefore do not analyse critically the criticisms of management accounting made by Goldratt, or examine the TOC model itself for potential flaws. However such flaws appear to be implicitly accepted by Jones and Dugdale (and indeed by Goldratt) in the narrative of how the TOC has evolved into a new managerial "philosophy" in later publications after "The Goal" such as "The Haystack Syndrome" (Goldratt 1990).

This later evolution redefined the objective of the firm from the maximisation of throughput contribution to a trio of much broader goals i.e. satisfying the needs of (1) the owners, (2) employees or (3) the marketplace. One of these three would be defined as the firm's objective subject to the other two acting as constraints. Significantly this shift to less specifically quantified objectives de-emphasises the allegedly revolutionary calculative components of the TOC. The rationale was to allow the TOC to evolve into a new "technology of thinking" or "Thinking Process", but which is less amenable to precise critical analysis. Significantly Noreen, Smith & Mackey (1995) reported that for most firms which claim to have adopted the TOC, or be influenced by it, it is the earlier and more quantifiable version of the theory which they follow and so it is still relevant to consider the metrics from an accounting viewpoint. In fact Noreen et al report "we were disappointed to see that it [the application of the Thinking Process] was used infrequently....at most sites it got almost no use" (p.138). It is also the "Throughput" formulation of TOC which has migrated into management accounting textbooks.

Jones and Dugdale accept the evolution of the TOC as congruent with the earlier model e.g. the hero of The Goal wanted to improve plant profitability in order to save jobs there are inconsistencies. However worker layoffs are implied in the original model where output must be restricted at non-bottleneck points in the production process in order to cut costs. In the later model such contradictions are reconciled by working to remove the constraint of limited demand by finding new customers or selling more to existing customers. This however "deals inadequately with conflicts of interest and marginalises the issue of management control" (p.88).

MANAGEMENT ACCOUNTING AND THROUGHPUT ACCOUNTING

Despite the rhetoric the ideas of TOC are congruent with the theory and practice of management accounting prior to the publication of The Goal. The goal of maximising Throughput Contribution while decreasing investment and operating costs can be seen as an approximation of the long standing accounting rule in short run decision-making of maximising contribution per unit of the limited resource which has featured in textbooks well before the Publication of The Goal. The Goldratt approach is often referred to as Throughput Accounting.

(However there is some ambiguity of language in that the term Throughput Accounting. In the US and continental Europe “Throughput Accounting” is the term used to refer to Goldratt's recommendations for accounting techniques. In the UK members of the Goldratt Institute avoid

using the term "Throughput Accounting" and uses the term "TOC in Accounting" instead. The reason is a dispute with Waldron and Galloway over the origin of the term.)

Goldratt's advocacy of marginal costing systems reflects the long standing criticism of absorption costing's weaknesses already prevalent in the accounting literature. The criticisms are therefore correct but unoriginal. They also fail adequately to recognise that accounting may use different costs for different purposes. The fact that organisations have complex absorption costing systems for financial reporting and inventory reporting systems does not preclude them from using marginal cost or variable costing information in at least some decisionmaking.

Clarke (1992) and Pierce & O'Dea (1998) both found almost identical usage rates for Cost-Volume-Profit (CVP) analysis of 85% or 82%. Although the Pierce and O'Dea study did find that the frequency of usage was low in many cases, the fact of any usage in a firm presupposed a split of costs into fixed and variable components being available.

The literature on TOC also goes beyond the accounting criticisms and attempts to demonstrate its superiority to the accounting model of marginal costing. In particular TOC recommends basing product mix decisions at the bottleneck resource on throughput contribution per unit of the limited resource, rather than accounting contribution margin per unit of the limited resource. For instance Atwater & Gagne (1997) purport to show how profit can be increased using the TOC approach by using the data in Appendix A, Exhibit 6. Their analysis appears that scarce machine time on machine 2 (the bottleneck resource) is best utilised when product P is prioritised using the TOC rule (Exhibits 4 and 5). In contrast the accounting rule would prioritise product Q (Exhibits 7 and 8). In Exhibit 9 the weekly profits of each are compared with TOC showing an apparently superior profit of $1,692 against only $1,630 for the product mix suggested by the accounting method.

What is key to understanding the difference is the final deduction of $3,000 for operating expenses in each case. The analysis is based on the assumption that no other variable costs except direct materials exist (despite the column 3 heading in exhibit 7). While this may be true in some cases TOC assumes that variable costs will never include any element of direct labour or variable overhead. Further the narrative of the article mainly argues reasons why this ***should be so***, rather than that it is so. The arguments used include indivisibility of the standard work-week, employee morale support from avoiding lay-offs and the value of retaining workers even when not productive through training etc. This analysis ignores real world phenomena such as part-time working,

contract working, overtime working and redeployment of idle staff from quiet to busy areas, all of which can be used to make labour costs variable at least at the margin, even without layoffs.

In fact if the Atwater & Gagne example were recast with direct labour also seen as truly variable then the results would be as follows:

Product ->	**P**	**Q**	**Total**
TOC METHOD – Production Plan			
Dir. Labour cost (per unit)	5.50	3.50	
Units produced	100	36	
Total direct labour cost	$550	$126	$676
ACCOUNTING METHOD – Production Plan			
Dir. Labour cost (per unit)	5.50	3.50	
Units produced	76	50	
Total direct labour cost	$418	$175	$593
Incremental direct labour cost from TOC production plan			**$ 83**

In the Atwater and Gagne paper (see Appendix A, Exhibit 9) TOC offers an increased weekly profit of $62 ($1,692 - $1,630). This is however based on the assumption that direct labour costs are unaffected by the production plan chosen and the advantage is reversed by the $83 extra in direct labour cost if labour is truly variable. The gap will grow wider if any of the overheads are truly variable and Appendix B shows how the difference in weekly profit could be as high as $120.

Balderstone & Keef (1999) suggest that the definition of throughput as sales minus only material costs is a result of a misreading of Goldratt's work, but even if this is so it has become the standard formulation of throughput contribution in both journals and textbooks as Balderstone & Keef themselves detail. In almost all cases direct materials costs are explicitly deducted while direct labour is not, while direct labour is usually explicitly or implicitly included in operating costs. In fact as they point out the error even extends to the Noreen et al (1995) independent report on TOC and its implications for management accounting (sponsored by The Institute of Management Accountants -USA), containing a foreword by Eli Goldratt and published by his publisher.

It is important to note that the mistaken belief that TOC provides a superior production planning tool to the marginal contribution rule in profit terms is not confined to the Atwater & Gagne paper.

It appears repeatedly in other papers, particularly in the field of production management e.g. Blackstone (2001), Umble & Umble (1998). Furthermore where the issue has been discussed in the accounting literature the discussion has tended to centre on pointing out the lack of novelty in the TOC approach, and that fact that it is a mere variation on the marginal contribution based accounting approach,(e.g. Dugdale & Jones (1998, p210)) rather than pointing out that it is actually inferior and potentially misleading.

THE ROLE OF OPTIMISATION

Some reviews of TOC assert that it provides additional insights beyond those available from linear programming (LP) e.g. "However, the level of analysis provided by LP via the shadow prices is not as detailed and does not provide the same level of analysis as provided by TOC through the $ return/constraint unit analysis" Luebbe & Finch (1992, p1477). This statement is misleading at best since in fact linear programming is based on the same principle of maximising contribution per unit of the limited resource. Each "pivoting" iteration of the simplex method which linear programming uses to solve optimisation problems is built on this principle. Unlike the TOC rule however linear programming runs through several iterations because it recognises the existence of several candidates for the role of binding constraint. TOC assumes that the choice of binding constraint will be intuitively obvious though build-up of work in progress inventory at particular points.

This intuitive or visible choice of bottleneck being readily available is not supported by the empirical evidence. Brausch & Taylor (1997) conducted a field study of 12 firms widely spread in size and industry sector to examine how firms managed, and accounted for scarce capacity. (The study in fact mentions neither TOC nor linear programming and so could be taken as 'value neutral'). It found that bottlenecks were more of a problem precisely in those nine firms of the twelve which made products with varying features using less continuous processes. While in some cases bottlenecks were entrenched at particular points, in other cases 'they are in flux due to changes in configuring the processes and in product mix, One obviously frustrated operations manager commented that in his company "bottlenecks are all over the place'". Tollington (1998) also distinguishes between long term constraints and "wandering bottlenecks" arising from unforeseen events. The proper identification of bottlenecks is likely to be a complex problem in practice. Salafatinos (1995) demonstrates the potential advantages of using techniques such as Activity Mapping and Activity Dependency Grids to identify the true source of bottlenecks since, contrary to much TOC literature, a buildup of WiP in front of one machine may have complex roots

elsewhere. He further shows how such mapping may double as support for developing an Activity Based Costing system.

In addition the shadow price is in a far more sophisticated measure than the TOC rule since it measures the marginal contribution from a scarce resource whereas the TOC measure only captures the average contribution (assuming that throughput contribution can be equated with classical contribution in line with the previous discussion above). For simple problems the marginal and average contribution will be the same, whereas for more complex problems they may well diverge.

Proponents of TOC claim that it does provide an extra insight in that built into the fifth step of TOC is the requirement to return to the start of the process once a constraint is broken e.g. as a result of making a process more efficient in its use of a scarce resource. As a result TOC ensures a cycle of continuous improvement where otherwise inertia would predominate. "We would continue to schedule production as if the system constraint had not changed and the improvement process would stop" Luebbe & Finch (1992). While this is self evidently true it ignores the fact that all linear programming models have a similar requirement to rerun the analysis once any value in a constraint changes.

THE CURRENT POSITION OF BOTTLENECK MANAGEMENT

While linear programming has clear conceptual advantages over TOC it has clearly had limited success in the marketplace for ideas. Clarke (1992) reports a usage rate of only 5% among Irish companies. There is also no evidence of increase in usage despite the increasing access to computer hardware and software and the spread of cost databases which could presumably lower usage cost. In fact some leading management accounting textbooks have dropped linear programming altogether from more recent editions while including TOC. Kaplan & Atkinson's second edition of "Advanced Management Accounting" (1989) devoted an entire chapter (cpt 3) to Linear Programming Models for Planning. The following edition (1998) contains no reference to linear programming, but does outline the TOC. "Cost Accounting: A Managerial Emphasis" by Horngren (1982, fifth ed. cpt. 23) and latterly by Horngren, Foster and Datar (2000 tenth ed.) follow a similar path.

It must be recognised that LP does itself have problems in implementation. These include its assumptions of:

-linearity in the objective function, and constraints.
-constant selling prices and variable costs, giving clear quantifiable coefficients for the objective function.
-identifiable and quantifiable discrete constraints. Brausch & Taylor (1997) found that none of their 12 research sites and only 3 of their 51 survey companies were determining available capacity, degree of usage and non-usage, or the cost of unused capacity in support areas and non-factory activities.

This paper can only begin to question the reasons for this shift from LP to TOC. It does seem to be part of a search for greater relevance and for academic text authors to follow those ideas attracting most attention in the popular business media and consulting markets, combined perhaps with students difficulty with more quantitative material. The origins of LP outside of industry in the military operations field (Pickering 1995) did not place it in the language or customs of business and as Pickering details there is a dialectic of resistance and accommodation between the purely technical and material and the human and social. It cannot be assumed that technical superiority assures automatic adoption.

TOC fits into a framework of crisis in accounting. Increasing competitive pressures in business arising from globalisation, deregulation and accelerating technological shifts are mirrored by anxieties in the literature over the future of management accounting. There is a marked search for new meanings, techniques and metaphors. “the decline of American manufacturing industry at root is held to be an acute failure of managerial expertise, and calculative expertise in particular” Miller & O’Leary (1993, p188). Perhaps TOC was an intuitively appealing tool in the right place at the right time.

POSITIVE INSIGHTS FROM TOC AND TRADITIONAL OPTIMISATION

The contribution of TOC may be to revive interest in an optimisation approach to capacity management, which although theoretically correct was not widely applied. It can be argued that the TOC approach should not be described as holistic (as it is in Tollington 1998, Noreen et al 1995) as for instance it does not recognise the possibility of adjusting pricing of marginal output to reflect dual prices of scarce capacity.

However the insight that management should constantly search out bottlenecks from obvious clues such as build up on WiP inventory, or customer queuing in the case of services. If this is followed by focused searching for relief of the bottleneck, as mandated by TOC then it can contribute to profitability. Brausch & Taylor's study outlined a variety of firm responses e.g. running overtime, extra days and extra shifts as well as outsourcing and employing temporary or seasonal employees in the bottleneck areas. Also the multi-skilling of employees may allow staff to shift from one area to another as short term conditions dictate. This should be supported by payment policies which recognise the acquisition of extra skills by employees and flexible working patterns. To be most effective in dealing with short term "roving" it needs to be built into long term strategy. A good example is the case of a multi-national high volume computer assembly operation, examined by this researcher, which rotates its production line staff across tasks every four weeks. It calculates that the productivity loss from unfamiliarity in the early stages of each person's learning a new task is repaid in the flexibility offered by multi-skilling (as well as improving output quality, absenteeism and high staff turnover through the reduced boredom of prolonged task repetition.)

More long term constraints may be addressed by investment in permanent additions to capacity. Again the TOC highlights the necessity for these additions to be tailored to relieving specific constraints rather than replicating entire production facilities, e.g. a new machine rather than a new factory may be sufficient.

Other approaches not often mentioned in the TOC literature may focus on management of the demand flowing into the bottleneck. Brausch & Taylor detail a tobacco company which addressed a bottleneck by reducing product proliferation, cutting its number of blends by two thirds.

Focusing exclusively on bottlenecks takes a narrow approach to managing capacity and capacity costs. Non-bottleneck areas also deserve attention. Balanced production may be achieved by short time working or layoff of contract staff in the short run, or by a process of disinvestment from surplus capacity, however Brausch & Taylor point out that none of the companies in their study accounted for the cost of unused capacity either at factory or non-factory locations. However in occasional cases they found that firms used marketing to fill the gap through obtaining special business from outside customers using special pricing. This echoes a common problem context of the Relevant or Marginal Pricing of a scarce order in accounting texts. An addition however is that the texts do not generally advocate that firms seek out such opportunities.

Costing Unused Capacity

Equally a balanced production process may have significant unused capacity. Brausch & Taylor's study found that in general firms do not capture the cost of unused or excess capacity. They recommend that firms explicitly quantify the lost contribution margin from unused capacity as a form of "waste" variance. An example of such a report at income statement level is given by Cooper & Kaplan (1992) as follows.

INCOME STATEMENT WITH UNUSED CAPACITY DISCLOSURE

Sales			$100,000
Less variable costs			70,000
Contribution margin			$ 30,000
Less Fixed costs			
	Used	*Unused*	
Process A	$ 6,000	$2,000	
Process B	$10,000	$4,000	
	$16,000	$6,000	$ 22,000
Operating Income			$ 8,000
			======

Income Maximisation from Marginal Pricing

The insight provided by linear programming of the marginal contribution to be gained from scarce resources has been operationalised in the airline industry in sophisticated yield management systems. These enable firms to practice price discrimination reflecting the degree of capacity filled on a flight based on current bookings and expected final capacity occupancy. Thus early bookers get cheaper tickets than those who have left themselves the flexibility of booking late (with final assessments of unused capacity leaving the possibility of cheap marginally costed seats for the least risk averse consumer. The transaction costs of such systems have fallen dramatically with the advent of internet booking which now accounts for a significant percentage of ticket sales.

CONCLUSION

The most significant question arising from this paper is not merely that the TOC's criticism of accounting metrics are flawed, or that its own metrics are merely simplified (and inferior) versions of other measures or methods in accounting and management science, and whose restrictive

assumptions apply in fewer cases than the models it draws on. Rather it is why the accounting literature has in many cases embraced what is effectively a regressive (or dumbed down) theory. This is interesting since narrative stands as a substitute for empirical evidence in most of Goldratt's work and he ignores academic debates on accounting theory and practice (Jones and Dugdale 1998). They point out that Goldratt almost never cites any other writer, although in presentations he frequently appeals to Plato and Isaac Newton.

Despite this Jones and Dugdale accept the TOC as having considerable potential as a theory of transformation. They claim it has "a methodology capable of directing change in specific ways, and it anticipates objections and hindrances so that they may be countered". This last point is at best arguable since it anticipates only selective objections and simply assumes away others e.g. in assuming that there is normally only one binding constraint which is clearly identifiable, and stable, it ignores the frequent inter-relationship of different constraints.

However TOC clearly has clear potential to act as a vehicle to encourage firms to adopt the marginal costing techniques for decision-making purposes recommended by the textbooks. An over-simplified applications of those principles is better than no application at all. It also directs managers to the strategically important insight that relative product profitability is unimportant, it the profitability of resource usage that matters, in particular the profitable use of the scarcest resources. In this it has emerged as a competitor for activity based costing in the popular marketplace.

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APPENDIX A

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EXHIBIT 2
Routing and General Information for Example Operation

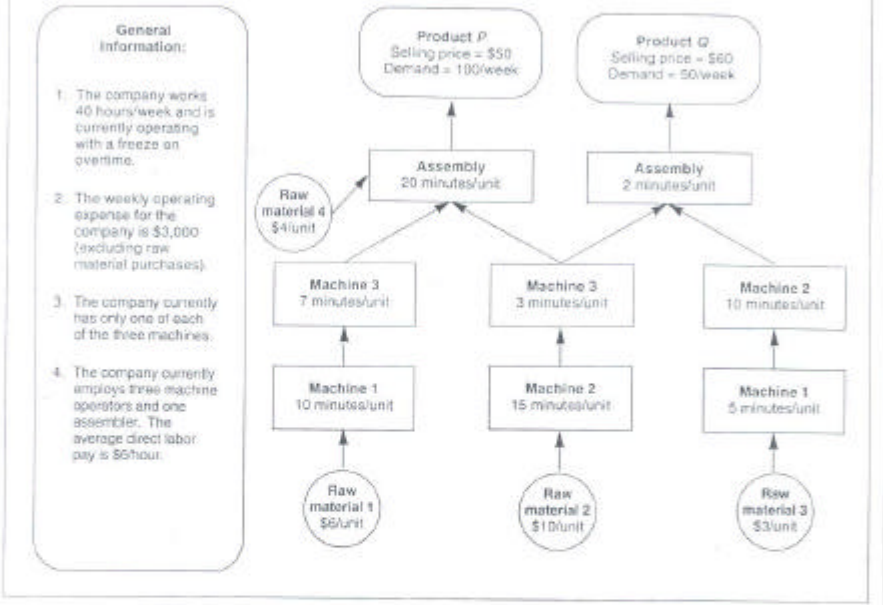

EXHIBIT 3
Capacity Requirements for Each Work Center

Machine Center 1

Product	Time	Weekly Demand	Capacity Needed
P	10	100	1,000
Q	5	50	250
			1,250

Machine Center 2

Product	Time	Weekly Demand	Capacity Needed
P	15	100	1,500
Q	25	50	1,250
			2,750

Machine Center 3

Product	Time	Weekly Demand	Capacity Needed
P	10	100	1,000
Q	3	50	150
			1,150

Assembly

Product	Time	Weekly Demand	Capacity Needed
P	20	100	2,000
Q	2	50	100
			2,100

EXHIBIT 4

Contribution/Constraint Utilization Using Throughput Value

1 Product	2 Selling Price	3 Raw Material	4 Throughput Value [2 – 3]	5 Time on Constraint	6 T/CU [4 / 5]	7 Production Priority
P	$50	$20	$30	15 min.	$2.00/min.	1
Q	$60	$13	$47	25 min.	$1.88/min.	2

EXHIBIT 5

Optimal Product Mix Using Throughput Value

1 Product	2 Capacity Available	3 Weekly Demand	4 Processing Time/Unit	5 Capacity Required [3 x 4]	6 Percentage of Market Demand Possible [2 / 5]	7* Optimal Quantity Produced
P	2,400 min.	100 units	15 min.	1,500 min.	160%	100 units
Q	900 min.	50 units	25 min.	1,250 min.	72%	36 units

* The number in column 7 represents the amount of each finished product produced each week. If the number in column 6 is greater than or equal to 100 percent, then all of that product needed to satisfy market demand is produced. If the number in column 6 is less than 100 percent, then that percentage of market demand for that product is produced.

EXHIBIT 6

Summary of Product Information Based on Exhibit 1

	Product *P*	Product *Q*
Weekly demand	100 units	50 units
Selling price	$50/unit	$60 unit
Time:		
Machine 1	10 minutes	5 minutes
Machine 2	15 minutes	25 minutes
Machine 3	10 minutes	3 minutes
Assembly	20 minutes	2 minutes
Total time	55 minutes	35 minutes
Raw materials:		
Raw material 1	$ 6/unit	
Raw material 2	$ 10/unit	$ 10/unit
Raw material 3		$ 3/unit
Raw material 4	$ 4/unit	
Total materials	$ 20/unit	$ 13/unit
Direct labor @ $6/hour	$5.50/unit	$ 3.50/unit
Variable overhead @ $0.05/minute	$6.60/unit	$ 4.20/unit
Throughput (selling price – cost of raw materials)	$ 30.00/unit	$47.00/unit
Contribution margin (throughput – direct labor – variable overhead)	$17.90/unit	$39.30/unit

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EXHIBIT 7

Contribution/Constraint Utilization Using Contribution Margin

1 Product	2 Selling Price	3 Variable Mfg. Costs	4 Contribution Margin [2 – 3]	5 Time on Constraint	6 CM/CU [4 ÷ 5]	7 Production Priority
P	$50	$32.10	$17.90	15 minutes	$1.19/minute	2
Q	$60	$20.70	$39.30	25 minutes	$1.57/minute	1

EXHIBIT 8

Optimal Product Mix Using Contribution Margin

1 Product	2 Capacity Available	3 Weekly Demand	4 Processing Time/Unit	5 Capacity Required [3 x 4]	6 Percentage of Market Demand Possible [2 / 5]	7* Optimal Quantity Produced
P	1,150 min.	100 units	25 min.	1,500 min.	76.7%	76 units
Q	2,400 min.	50 units	25 min.	1,250 min.	192.0%	50 units

* The number in column 7 represents the amount of each finished product produced each week. If the number in column 6 is greater than or equal to 100 percent, then all of that product needed to satisfy market demand is produced. If the number in column 6 is less than 100 percent, then that percentage of market demand for that product is produced.

EXHIBIT 9

Weekly Profit of the System With Each Product Mix

Throughput Value		
Revenues:		
P (100 units x $50/unit)		$5,000
Q (36 units x $60/unit)		2,160
Total revenue		$7,160
Less raw material costs:		
P (100 units x $20/unit)	$2,000	
Q (36 units x $13/unit)	468	(2,468)
Total		$4,692
Less operating expenses:		(3,000)
Weekly profit		$1,692
Contribution Margin		
Revenues:		
P (76 units x $50/unit)		$3,800
Q (50 units x $60/unit)		3,000
Total revenue		$6,800
Less raw material costs:		
P (76 units x $20/unit)	$1,520	
Q (50 units x $13/unit)	650	(2,170)
Subtotal		$4,630
Less operating expenses:		(3,000)
Weekly profit		$1,630

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APPENDIX B

Weekly Profit of the Firm with each Product Mix

Throughput Value based production plan

Product	**P**	**Q**	**Total**
Units	100	36	
Revenues (P @$50/unit, Q @$60/unit)	5000	2160	7160
less Raw Materials (P @$20/unit, Q @$13/unit)	2000	468	2468
less Dir. Labour (P @$5.50/unit, Q @$3.50/unit)	550	126	676
less Var. Overhead (P @$6.60/unit, Q @$4.20/unit)	660	151	811
less Other Operating Expenses (assumed Fixed)			1400
Weekly Profit			1805

Contribution Margin based production plan

Product	**P**	**Q**	
Units	76	50	
Revenues (P @$50/unit, Q @$60/unit)	3800	3000	6800
less Raw Materials (P @$20/unit, Q @$13/unit)	1520	650	2170
less Dir. Labour (P @$5.50/unit, Q @$3.50/unit)	418	175	593
less Var. Overhead (P @$6.60/unit, Q @$4.20/unit)	502	210	712
less Other Operating Expenses (assumed Fixed)			1400
Weekly Profit			1925
Increase in Weekly Profit			120