

## The theory of constraints and the make-or-buy decision: an update and review.



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The make-or-buy decision has traditionally been made using standard cost accounting methods. In this Journal, Gardiner and Blackstone (1991) made a strong case for incorporating the bottleneck capacity into the decision. However, their method did not guarantee the best solution for the more complicated make-or-buy problem. Additionally, their approach in some cases allowed organizations to forego opportunities for profit improvement. Since the publication of the Gardiner and Blackstone research, spreadsheets with in-built Linear Programming (LP) based optimizers allow for quick "what-if" analyses that encourage efforts toward optimal solutions for complicated problems. This article is a review and update of the Gardiner and Blackstone methodology based on spreadsheet LP that provides enhanced solutions in complex environments with multiple products and bottleneck situations. Specific managerial implications are offered.

### INTRODUCTION

The thrust of this research is on a make-or-buy decision method that combines traditional cost accounting and the effects of capacity limitations. It is shown that if these two factors are not considered simultaneously, the firm may incur unnecessary additional expenses as a result of suboptimal make-or-buy decisions. The work of Gardiner and Blackstone (1991) provides the methodological underpinnings of the current research. However, the method described in that research did not guarantee the best solution for the more complicated make-or-buy problems that permeate complex supply environments.

Another important advantage of the proposed method is that a spreadsheet-based optimizer is used for more effective implementation. Thus, the current method offers an approach that gives optimal solutions and at the same time takes advantage of a widely used medium, the spreadsheet, for implementation. The recommended approach should offer more practical applications to supply decision makers.

### OUTSOURCING RESEARCH AND CONTRIBUTIONS OF THIS ARTICLE

The make-or-buy issue involves determining whether a particular component should be made in-house or purchased. It is one of the most important decisions for many manufacturing organizations as they rationalize their supply chain for improved productivity and profit (Matthews 2000). Increasingly, make-or-buy decisions have enormous strategic implications. That has become even more the situation given the complexity of the purchasing and supply environments. Research by Prahalad and Hamel (1990), Porter (1991), Venkatesan (1992) and Sturgeon (2002) focused on strategic and organizational issues, such as core competence and organizational flexibility, which address directly the significance of make-or-buy decisions. More specifically, Hoyt and Lee (2001) discussed the evolution of outsourcing, and the resulting strategic implications, from the perspective of a particular industry.

A major issue in make-or-buy is to distinguish between strategic and nonstrategic parts. Generally, strategic parts are produced in-house for competitive reasons. For example, Honda is unlikely to outsource its engine manufacturing, given that engine design and manufacturing constitutes a critical portion of its core competence. Outsourcing engine design could possibly result in Honda becoming vulnerable strategically. On the other hand, items such as batteries that are considered standard items are not part of its core competence. Thus, both Honda and the battery supplier would concentrate on their core competencies, in the expectation of a win-win situation. Other strategic issues in make-or-buy include the cost of the updated technology required to continue manufacturing the part

in-house, asset utilization, the possibility that outsourcing might reduce significantly the barriers to entry (generating more competition), or reduce the company's leverage in the supply chain, and whether it would hinder or help time-to-market for new products. Organizational issues include the ability to change the firm in order to reflect any adjustments in the future supply chain, and the ability to cooperate with suppliers and to properly manage the outsourcing function.

While these and other strategic issues, such as uncertainty in technology and volume, and competition among suppliers are important in the make-or-buy decision (Walker and Weber 1987), financial implications are also important (Burt et al. 2003). This financial analysis often uses traditional cost accounting measures, but these measures do not examine the effect on the existing products when a purchased component is brought in-house for production. Recent publications using traditional cost accounting for the make-or-buy decision include van Damme and van der Zon (1999). However, they do not address the issue of capacity constraints. The importance of capacity constraints in sourcing was alluded to briefly by Anderson and Katz (1998), but their research did not offer a detailed analysis useful for decision making.

Thus, little research has focused on the integration of operational and managerial accounting issues in the make-or-buy decision. As indicated in Blackstone and Gardiner (1991), it is important to take an integrated approach to make-or-buy. Given the increasing frequency of outsourcing decisions, and the underlying complexities associated with this process, it is essential to have an integrated and comprehensive methodology as part of the decision-making process. Given the practical importance of outsourcing, it has also spawned the need for more substantive and definitive research on all aspects of the make-or-buy decision. Further, due to globalization, it is also becoming an increasingly complex topic. Thus, there is a need for models reflective of the current environmental realities confronting managers in the make-or-buy arena. This means integrating operational and financial aspects of the make-or-buy decision.

This article focuses on the tactical issues in the make-or-buy decision. Assuming the organization has decided that certain parts are candidates for outsourcing, the proposed model assists in deciding which products to purchase and which ones to produce in-house. The Blackstone and Gardiner (1991) approach illustrated a basic issue in make-or-buy--that capacity issues must be integrated with financial issues for better decisions. The current research extends this model further to reflect the increased ability of decision tools to accurately model the realities of outsourcing. Thus, the current research initiative provides researchers with more insight into the outsourcing decision and provides a springboard for additional scholarly investigation.

## THE TOC APPROACH TO THE MAKE-OR-BUY PROBLEM

The Theory of Constraints (TOC) was used by Blackstone and Gardiner (1991) to analyze the make-or-buy decision. The TOC advocates managing by focusing on the removal of the constraints in a system in an effort to enhance profitability. These constraints may be physical, such as machine capacity, or may be some management policy such as pricing. The TOC has five steps that imply continuous improvement:

1. Identify the system constraints. This is analogous to identifying the weakest link in the operations chain, the link that limits the system's capability.
2. Decide how to exploit the system constraints; i.e., maximize the performance of the system given the constraints identified in Step 1.
3. Subordinate everything else to that decision. The rest of the system should be geared toward helping achieve Step 2, even if it means inefficiency in the other parts.
4. Elevate the system constraints; i.e., if performance is not satisfactory, acquire additional amounts of the constrained resource.

5. Return to Step 1 for improvement if the previous steps result in new constraints.

Several techniques such as drum-buffer-rope, evaporating clouds, and cause-and-effect analysis are used in the TOC process of continuous improvement. Rahman (1996) provided a detailed review of the TOC literature and applications to various business problems. More recently, Blackstone (2001), in an update on the field, showed how TOC techniques such as drum-buffer-rope, evaporating clouds, and reality trees can be used in performance measures, supply chains, marketing, and managing people, in addition to the traditional production applications. Goldratt (1997) was successful in re-emphasizing the importance of process bottlenecks. While the role of bottlenecks (through management by constraints) in process management has been recognized for a long time, Goldratt was successful in translating these bottleneck issues into principles useful to both practitioners and academicians. In his book *Critical Chain*, Goldratt (1997) indicated that TOC principles are applied in project management, emphasizing the importance of resources on project scheduling. For a critical review of the TOC principles, see Trietsch (2003).

Traditionally, this decision was made based on standard costs. Gardiner and Blackstone (1991) discussed the influence of shop-floor capacity on the make-or-buy decision. If the component being considered for in-house production has to share a resource with existing products and this resource is being fully utilized at present, then the only way to produce this new component is by taking capacity on that resource away from existing products, which could adversely impact profitability. The contribution per constraint minute (CPCM) criterion discussed by Gardiner and Blackstone (1991) addresses this issue. The CPCM is the contribution generated when a bottleneck resource contributes one minute to the processing of a product. They showed that the standard cost method for making the outsourcing decision is inferior to the CPCM approach. From a managerial accounting perspective, the CPCM follows the TOC principle of variable costing where labor is considered fixed (Noreen et al. 1995). The Gardiner and Blackstone (1991) example consisted of a one-product, one-bottleneck situation where one of the components of the product could be purchased.

The advantage of the CPCM method over standard costing can be illustrated using Example 1. Product M is sold for \$174 per unit. It requires the processing of \$4 worth of raw material on Workstation A for 15 minutes. Then it is processed on Workstation B for 20 minutes, after which it goes to final assembly where component C is inserted (for simplicity the assembly time is negligible). Prior to this, component C also must be processed on Workstation B for 12 minutes and uses \$6 worth of raw material. Thus, in total, 32 minutes of processing on Workstation B is required for the completion of Product M, making it the only bottleneck or constraint. The weekly capacity of each workstation is 2,400 minutes. The labor rate is \$20 per hour and the variable overhead is \$30 per hour. Alternately, component C can be purchased for \$29 per unit. The company can sell as much as it makes. Table I shows the make-or-buy analysis using standard costing.

Based on this analysis, it is more profitable to make this product. Note that there is no consideration of the effects of the make-of-buy decision on production capacity.

The CPCM focuses on Steps 1 and 2 of the five-step TOC process. Thus, the CPCM helps identify the constraint and exploits it. It also helps identify the resources that should be elevated (acquired) in Step 4. The CPCM incorporates both the savings in costs due to avoiding the higher purchase price as well as the decreased profit due to taking resources away from other products. If the CPCM value is higher for the "make" option, it implies that the decreased profit due to taking resources away from other products is more than offset by not incurring the purchase price and vice versa. Thus, it provides better results than the traditional costing approach, which ignores the resource trade-off. The non-bottleneck resources (Workstation A and final assembly) are ignored as they have idle time and thus they will not be affected by the introduction of this new component into the system. The CPCM analysis for Example 1 is shown in Table II.

The analysis in Table II shows that the CPCM for the "buy" option in Row 5 is higher than for the "make" option. Thus, the component should be purchased because the purchase price avoidance savings from making component C is not enough to offset the loss due to the reduced production in M (Row 7) when some of the bottleneck capacity is allocated to C in the "make" option. This reduced production in turns results in lower total contribution (Row 8) for the "make" option.

So the CPCM is a better criterion than standard costing in determining the make-or-buy decision. However, the CPCM method also has some shortcomings. A review of the more recent literature, which combines TOC and traditional costing, by Kee and Schmidt (2000) reveals that these shortcomings have not been addressed in the make-or-buy context. This is addressed next using Example 2 in the following section.

## THE MAKE-OR-BUY DECISION WITH MULTIPLE PRODUCTS AND BOTTLENECKS

Consider Example 2, where a company produces two products, P and Q. Figure 1 shows the product tree. Both products must be processed on machines A, B, C and D with the processing times shown in the figure. Each unit of P requires \$20 worth of raw material (RM1) and sells for \$174, while each unit of Q requires \$10 worth of raw material (RM3) and sells for \$159. Moreover, with each product, one of the required components can be purchased or made in-house. For P this component, called P(c), costs \$29 per unit if purchased. If made in-house, the raw material (RM2) cost is \$4 per unit, and it needs to be processed on machines B, C and D and then assembled at machine A as indicated. In the case of Q, component Q(c) may be purchased for \$33 or produced in-house using the same raw material as for P(c) for \$4 and then processed as shown. However, note that the processing times to produce P(c) and Q(c) are different, so they are actually different items. The market demand for each product is 100 units. Each machine has 2,400 minutes available for processing. The issue here is to determine the most profitable product mix and also to decide whether to purchase P(c) and Q(c) or to make them in-house.

[FIGURE 1 OMITTED]

In order to do this, the CPCM criterion is used. Initially, a spreadsheet is set up as shown in Figure 2 to determine the constraint. In Figure 2, the range E25 to H28 gives the processing times on each machine for P, Q, P(c) and Q(c). The range 125 to 128 shows that the maximum time available on each machine is 2,400 minutes. The range E8 to H8 gives the units of P, Q, P(c) and Q(c) produced in-house and sold, respectively. In order to determine the constraint or bottleneck machine, it is assumed that all market demand is satisfied and that P(c) and Q(c) are produced in-house, thus giving the maximum possible usage of the four resources. Therefore, 100 units each of P, Q, P(c) and Q(c) are assumed to be produced. The range E17 to H20 shows the minutes required on each machine for P, Q, P(c) and Q(c) for this production plan.

[FIGURE 2 OMITTED]

The advantage of a spreadsheet is that relationships can be set up quite easily. For example,  $E17 = E8 * E25$ . This logic can be copied to the other cells in the E17 to H20 range. The range I17 to I20 determines the total usage of each machine. This must be less than or equal to 2,400. Finally, the range L17 to L20 gives the utilization of each machine. It is clear that machine B is the only one that is overloaded (more than 100 percent utilization). Hence this is a two-product one-bottleneck case. Based on the TOC, resource B would be the system constraint. To exploit the constraint, Figure 3, which is similar to the decision table used in Gardiner and Blackstone (1991), is examined. Note that the contribution margins in cells E9 and F9 of Figure 2 come from the contribution margins for the "make" options for P and Q in Figure 3. Cells G9 and H9 in Figure 2, which represent the additional contribution margins if P(c) and Q(c) are made in-house, are also determined from Figure 3 as follows.

If P(c) is made in-house, the contribution margin for P would increase by the difference between the Make P(c) and Buy P(c) material costs: i.e., (\$29-\$4) or \$25. Similarly for each unit of Q(c) produced, the contribution margin for Q would increase by \$29. It is important to remember that this additional contribution of \$25 or \$29 also results in the increased use of resources. Thus, when P(c) or Q(c) is made in-house, the corresponding times on the machines are added in the relevant cells in the range E17 to H20 (Figure 2) to reflect the additional processing times.

To determine the make-or-buy decision based on the TOC, the CPCM numbers for resource B (the constraint) in Figure 3 are examined. For item P since 8.06 is less than 8.11, it is concluded that it is better to make P(c). For item Q since 8.92 is greater than 8.79, it is concluded that it is better to buy Q(c). This is equivalent to saying that the decision is to make P, P(c) and Q while purchasing Q(c). As there is not enough capacity to satisfy market demand for all of P, P(c) and Q (this can be easily confirmed from the spreadsheet), the priority for fulfilling each product's demand also must be determined. Since producing Q and buying Q(c) has a higher CPCM (8.92) than making P and P(c) (8.11), the demand for Q gets first priority, resulting in the production of 100 Qs (and purchasing 100 Q(c)s). By trial and error, it can also be determined that there is enough capacity left to produce 59.45 Ps and 59.45 P(c)s as seen in Figure 4. The total contribution margin is \$20,517.50. However, it is possible to find a better solution with a higher total contribution as shown in Figure 5. This was obtained using a spreadsheet-based LP optimizer add-in.

[FIGURE 3 OMITTED]

[FIGURE 4 OMITTED]

This suboptimality occurs because the CPCM numbers based on Gardiner and Blackstone's (1991) method (shown in Figure 3) are not detailed enough in the two-product case. If Q were the only product, the make-or-buy decision would be for Q(c) only based on the trade-off at resource B. However, with the existence of product P, the trade-off on resource B between P and P(c) on one hand and Q(c) on the other must be examined. The CPCM analysis is not able to make this trade-off effectively. LP, on the other hand, is guaranteed to give the best solution.

The situation also becomes more complex if there are multiple bottlenecks; i.e., more than one machine has a projected utilization of 100 percent or higher to satisfy demand. Again, it can be shown that the CPCM can give suboptimal results while LP will give the optimal solution.

When there are multiple products or bottlenecks, in addition to suboptimal solutions, there also can be errors in evaluating the effect of an increase in the available capacity of bottleneck machines, when using the CPCM method. Since the CPCM may not use the bottlenecks in an effective manner, it may recommend increasing the capacity at the wrong bottleneck machine (in Step 4 of the TOC), which may result in forgone additional profit. In addition, the CPCM method may also ignore improvements in productivity of a non-bottleneck machine, when in fact that improvement could have been translated into additional profit, through product mix adjustments. LP, with its ability to answer what-if questions in an optimal manner, can provide valuable assistance in these situations. For additional details on LP modeling using spreadsheets, refer to Winston and Albright (2003).

[FIGURE 5 OMITTED]

## MANAGERIAL IMPLICATIONS

Outsourcing has become one of the most critical decision areas in modern business. Outsourcing is evident across a wide array of industry sectors and is common-place in organizations where the products are closely identified with the organization itself, thus

allowing more effort and resources to be devoted toward enhancing areas of core competence (Matthews 2000; Pitts 2003). Even when a product is not outsourced permanently, companies often temporarily use other firms for product assembly. Given the increased frequency and complexity of outsourcing-related decisions, it is imperative to have sound operational methodologies to assist in this process. The current study offers detailed explanations of how managers can use multiple approaches, including TOC and LP modeling, to improve decision making. A detailed example was presented, explained and analyzed and supports the importance of an integrative approach to outsourcing.

The article also integrated both Management by Constraints (MBC) (Trietsch 2003) and the Theory of Constraints (TOC) philosophy (Goldratt 1990). Collectively, these two approaches offer insights regarding the management of the make-or-buy decision-making process in organizations. Finally, the article demonstrated how a computerized decision support tool, specifically spreadsheet LP, enhances efforts to convert management thought into practice, as demonstrated by the comparisons between the standard cost approach to both TOC and CPCM.

## LIMITATIONS AND FURTHER RESEARCH

Since LP was used as the decision tool, some of the limitations in this research arise from the use of this methodology. For example, if the prices of different components or parts vary simultaneously because of global price fluctuations, the problem may have been re-optimized multiple times in a "what-if" format. Further, if machine breakdown resulted in changes in capacity, the solutions provided by LP might not be implemented as easily. If uncertainty is a major concern, other tools such as computer simulation may have to be used to examine the robustness of a decision. Further, if the problem is very large or complex, non-spreadsheet-based LP optimizers may be needed.

The problem is also modeled based on a single objective, cost minimization. In practice, the decision maker may have multiple objectives such as making the cost-quality trade-off between suppliers, assessing the supplier's reliability, technical capability, financial strength and so on. As competition increases, it is important to have a supplier with multidimensionality, which correspondingly increases the complexity of the outsourcing decision. Given this backdrop, future avenues for research could include using multiple-objective decision tools such as Goal Programming (a variant of LP) or the Analytic Hierarchy Process (AHP) (Saaty 1980). Further research might also involve some of the make-or-buy considerations not included in this article. For example, if a product is outsourced, there might be an implied fixed cost associated with managing the outsourced product. If multiple suppliers are offering the same part, one consideration might be the possible economies of scale derived if the contract was offered to an existing supplier. There also could be interactions between the products themselves. For example, if two products use similar resources in design and manufacturing, a relevant research issue would be whether outsourcing one might result in the diminished ability to produce the other effectively. Incorporating these issues would make the problem more comprehensive for actual situations confronting outsourcing decision makers in organizations.

## CONCLUSIONS

Gardiner and Blackstone (1991) showed that using the traditional costing method to decide whether to make or buy an item could result in poor decisions because it ignores the capacity aspects. Their research therefore makes an important contribution in understanding the make-or-buy decision. However, their procedure may not result in good decisions in the more complex make-or-buy situation. In this article, it was shown that spreadsheet LP, which has become popular since the publication of the Gardiner and Blackstone (1991) article, can provide optimal decisions and what-if capabilities in a readily available manner. Some future avenues of research in this area were also identified.

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