A Quantitative Model for Understanding Multiple Vendor IT Outsourcing

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Abstract

In this research, we analyze Information Technology (IT) outsourcing decisions involving multiple vendors and apply modeling techniques to systematically evaluate such outsourcing decisions. We take costs of in-house production, outsourcing, and coordination into consideration simultaneously. Further we also consider the performance of vendors. To make our work more adaptable, we make different assumptions on the interaction of different jobs. For a case considering the interaction of a pair of jobs at a time, a linear model is formulated. An example problem is solved using a practical spreadsheet based optimizer and the managerial use of this model in decision support is emphasized. For a case considering multiple-way interactions among jobs, we formulate a non-linear model. We discuss how to reformulate and solve an equivalent linearized model. An example problem is also presented for illustrative purposes.

Keywords: Information Technology, Outsourcing, Multiple vendors, Vendor selection, QAP

1. Introduction

The concept of Information Technology (IT) function outsourcing is not new. According to Klepper and Jones (1998), IT outsourcing can be traced back to 1954 when General Electric entered into outsourcing contracts with Arthur Anderson and UNIVAC. Back then, the maintenance of computer facilities was very expensive and hence it made sense to have contractors do it. Further, Teng et al. (1995) argued that firms often outsourced their operational and facility management services to avoid heavy initial investments. The interest in outsourcing seems to have waxed and waned in the past half century. In the 1970s, firms saw the need to develop customized software [Ketler and Walstrom (1993)]. As a result, the demand for software development increased and many managers considered outsourcing their software development through contract programming. This might have been partly due to the fact that managers were unfamiliar with software development and possibly because there was an insufficient supply of software engineers. Later in the 1980s, the IT functions were viewed by many firms as part of their strategic competency to support vertical integration. Firms began reversing the practice of outsourcing and began to bring their IT functions in-house. Today however, outsourcing has become popular again. Outsourcing is being seen as an approach for releasing management resources, sharing costs, creating integrated networks, building new organization structures, staff training, and interfacing with other information systems [Ryans (1996)].

Although outsourcing has been widely adopted in the industry, many IT based outsourced projects still fail. According to Maclnnis (2003), about one quarter of outsourcing contracts examined failed in the first year and half of the outsourcing companies renegotiated their contracts or simply switched to other vendors. Haubold (2000) also showed that only 16.2 percent of outsourcing projects were completed on time and within budget. In addition, more than 31 percent of them failed and were suspended.

Thus IT outsourcing deserves more research attention. Using secondary research data, Wang et al. (2008) found the outsourcing benefits were found mainly at the process level than at the firm level. In addition companies that had better core IT capabilities were better able to leverage outsourcing to enhance firm value. Jorgenson (2009) suggest strategies that prevent selecting software bids that have optimistic cost estimates. Liu and Yetton (2009) pointed out that in outsourcing, project sponsorship especially at the vendor level has rarely been studied. Through an empirical study they found that such sponsorship can help timely completion of the project. Krishnamurthy et al. (2009) describe a strategic model for outsourcing used at Cisco. While traditionally IT outsourcing results in compromises and tradeoffs, the authors claim that using the Cisco model reduces these. Whitten and Leidner (2006) examined the factors that caused clients to switch vendors or bring the function back in-house. They found

that relationship quality, such as trust were more important than product or service quality in switching but both were important in bringing the function back in-house. Bullen et al. (2007) surveyed IT managers in order to determine the skills that were perceived as important to retain in-house versus those that could be outsourced. It was found that the non client facing technical skills are the most likely candidates for outsourcing.

In the literature, researchers have examined outsourcing practices from different perspectives and by using different approaches. However, Cheng et al. [2006] observed that few analytic models were available to help analyze IT outsourcing decisions systematically. To address this problem, they proposed a new decision model. Their outsourcing model considers various factors that may implicitly or explicitly influence the outsourcing cost. However, their model can only deal with the single vendor situation.

In this research, we propose new models for outsourcing involving multiple vendors. In reality, firms may outsource to different vendors at the same time. The multiple vendor approach to outsourcing provides many advantages, such as reduced reliance on a single vendor, improved product and service quality, lower prices through competition, etc. Hence, our models may be more useful to managers. In addition, we make use of Excel Solver to solve the problem. Solver is a free add-in package for Excel and a more powerful version – Premium Solver – is commercially available. This provides an opportunity to show to managers how a computerized decision support tool, specifically linear programming on a spreadsheet, enhances efforts to convert effective ideas into managerial practice. Further we show that many managerial considerations in outsourcing can be better analyzed using spreadsheet modeling. To make our work more practical, we also show that this problem can be formulated in general as the quadratic assignment problem (QAP) to address the multiple-way interaction among jobs. The non-linear model can be transformed into an equivalent linear model. An example problem is solved based on the equivalent linear model.

This manuscript is structured in the following manner. A literature review is provided in Section 2. Modeling considerations are presented in Section 3. A simple model is proposed Section 4. An example problem is solved. Several aspects of what-if analysis are discussed. In Section 5, a more complicated model is proposed. The model is transformed into an equivalent linear model. A numerical example is also solved. Section 6 concludes the paper.

2. Literature Review

In the literature, most outsourcing research studies are descriptive and somewhat anecdotal. Few use mathematical models. In this review, we concentrate on quantitative models.

AHP has been a popular method in outsourcing and vendor selection. Udo (1996) argued that the Analytic Hierarchy Process (AHP; Saaty, 1990) was a good analytical tool to handle complex outsourcing decisions systematically. Their AHP outsourcing decision model considers four categories of factors in the analysis: strategic importance, vendor issues, customer's interests, employee's interests. Other factors may be added to the hierarchy to address the special circumstances of a company.

Yang and Huang (2000) also used AHP to develop an outsourcing decision model that included five factors: management, strategy, economics, technology and quality. The model helps a user structure the outsourcing problem with all the elements or factors that may be important to the decision. It also provides the user with a systematic way to analyze factors or attributes, and to prioritize jobs to be outsourced. Johnson Rajkumar et al. also use AHP in vendor selection based on four main criteria, quality, price, delivery, and customer focus. Each of these had multiple sub criteria.

Patterson and Rolland (2002) developed a bias-free decision model to aid the E-business outsourcing process using linear programming calling it the Capacitated Business Process Outsourcing problem (CBPO). The model finds the assignment of processes to providers such that the total operating expenses are minimized. Paisittanand and Olson (2006) used a Monte Carlo simulation model to examine the risks involved in IT outsourcing at the credit card business of a major Thai bank. The analysis gave the organization more confidence in making the decision.

Gottschalk and Solli-Sæther (2005) in an empirical study found that reducing transaction cost, which we address in this research, was a critical factor in IT outsourcing success. Foogooa (2008) states that as more companies move to strategic outsourcing, multi-vendor as opposed to single vendor contracts become more common. Dhar and Balakrishnan (2006) discuss the different risks involved in outsourcing which includes the costs involved bargaining and opportunism, which we include in our model.

Cheng et al. (2009) examined the outsourcing practices of eight small and medium software providers in Hong Kong. All these companies had outsourced work to China, primarily for cost reasons. The authors recommend that only vendors with a track record be selected and only non core activities such as coding be outsourced. Also it was recommended from a intellectual property protection perspective that the project be broken up into subprojects and the different subprojects be outsourced to different vendors. They also emphasized the coordination required by the customer and vendor (and by implication, between different vendors), in managing the outsourced work. Thus this paper clearly illustrates the importance of considering multiple vendors in outsourcing models. Kanagaraj and Jawahar (2009) identify the various pieces of research that deal with vendor selection.

Some of these are mathematical programming models. But all these are related to purchasing physical products and in determining the quantities to be purchased.

Most research models in IT outsourcing including Patterson and Rolland (2002) treated every outsourcing decision as an independent event and ignored the importance of the inter-dependence among the IT functions. Masten (1984) and Gulati (1995) argued that this "independent" treatment in modeling was inappropriate.

Cheng et al. (2006) develop a model to address this limitation. Compared with the existing models, their model is unique in two ways. It not only considers the inter-related nature of jobs but also takes the performance of vendors into consideration. However, they only examine a single vendor situation. As we have argued earlier on in this manuscript, a multiple vendor approach to outsourcing provides additional advantages. A model incorporating this feature will be valuable to firms that are interested in considering and maintaining a multiple vendor relationship. Hence, we propose a new decision model that considers multiple vendors. We believe that this paper fills an important gap in existing research, since to the best of our knowledge, a mathematical programming model of the multivendor IT outsourcing decision with the co-ordination considerations has not been proposed thus far.

3. Modeling Considerations

Our model considers many factors that explicitly or implicitly influence the outsourcing cost. Our mathematical model is based on the costs including fixed costs for both in-house and outsourced jobs, transaction costs such as those of bargaining and opportunism, and the costs due to the interrelationship between the different jobs.

3.1 Fixed cost for in-house and outsourced jobs

The fixed cost for in-house jobs includes the set up cost for establishing a service such as the permanent personnel, technology, and control systems. It also includes the coordination and monitoring costs for internal operations. However, the resources required for in-house production related to labor, computer facilities and expertise cannot exceed the maximum capacity of the firm. The fixed cost for outsourced jobs is the price quoted by the vendor includes the set-up cost for performing the work, the costs for establishing a relationship with the outsourcer and any contracting costs to handle the process. Nevertheless, this quoted price does not necessarily reflect the actual cost to the outsourcer and does not include any transaction costs that may be required for governing the transaction.

3.2 Expected transaction costs

These include costs related to bargaining and opportunism that arise in governing outsourcing activities. Bargaining costs can arise from negotiation and monitoring which can happen in the pre- during and post-contractual stages. In bargaining both parties are acting in their self interest but in good faith (Williamson, 1985). An example would be a vendor attempting to reopen a contract because of steep raw material price increases. Opportunism refers to a vendor who attempts to change the agreed upon terms of the contract to enhance its self-interest but in bad faith (Vining and Globerman, 1999). An example would be a vendor that demands a higher price than was agreed upon because it sees the outsourcer in a weakened position. These costs can be estimated by the outsourcers based on the performance history of the vendors.

3.2.1 Vendor Performance Matrix

The expected transaction costs can be estimated by the outsourcer using a vendor performance matrix (Soukup, 1987). The matrix is designated to analyze the transaction costs that may occur depending on an individual vendor's performance. The performance of the potential vendor is extremely important in IT functions and failure in achieving the expected level of performance will lead to additional costs (Bender et al., 1985).

Since the vendor selection process is very critical in making outsourcing decisions, various criteria must be considered in order to find the most suitable vendor to accomplish the task. Dickson (1966) studied 23 vendor selection criteria which are still considered to be relevant in making outsourcing decisions (Weber, et al., 1990). The top ten selection criteria are quality, delivery, performance history, warranties and claim policies, production facilities and capacity, price, technical capacity, financial position, procedural compliance and communication system.

To create the vendor performance matrix, the manager will have to evaluate each vendor's potential performance on each job based on these criteria to generate an overall score. Based on this overall score, the transaction costs that will be incurred under different performance levels will have to be estimated. The probability of the occurrence of each level also has to be estimated. Once this is done a weighted average (expected) transaction cost can be generated. Table 1 is an example of this process where vendor's performance is assigned to Good, Fair and Poor categories.

Table 1: Expected transaction cost for a hypothetical job and vendor ($ millions)

Performance (A)	Cost (B)	Probability (C)	Weighted Cost (D)
GOOD	0.01	0.25	0.0025
FAIR	0.25	0.55	0.1375
POOR	0.50	0.20	0.1000
Resultant expected transaction cost (Sum of Column D)			0.2400

3.3 Coordination cost among jobs

Since IT functions may be interrelated, the performance on one job may affect the performance on another due to the required coordination and reliance. This factor can be very significant in the multiple vendor approach since different vendors would have different capabilities and performance levels. For example consider two interrelated jobs that are candidates for outsourcing. If both are done in-house the coordination between them may be managed easily. Outsourcing only one of them might result in coordination issues and higher coordination costs since the coordination now involves a contractor outside the organization. For example, one IT job (e.g. training), that may have high reliance and dependence on another job (e.g. system development and planning), may be risky to outsource. It may be better to do the job in-house due to better coordination and monitoring of the interrelated functions. On the other hand, another IS function (e.g. PC maintenance), which may not be strategic and has a low dependence on another job (e.g. system development), could be outsourced with minimal risk since it has low interrelationships with other jobs. Also different vendors may have different capabilities in this regard which may affect this coordination cost. Further one vendor may be able to do both jobs, which implies that we may be able to outsource both jobs while another vendor may be able to do only one of the jobs. This again may affect the total coordination costs. Thus, an inappropriate combination in assigning the two jobs can result in unnecessary coordination costs. The proposed model thus considers the inter-dependence and coordination between any job and other jobs before determining whether the job should be outsourced. In our model, we consider pairs of jobs at a time. There are only five possible scenarios of assigning each pair of jobs. This is explained in the next section.

The pair-wise comparison model will be used to illustrate the advantages of the model from an optimization and what-if scenario perspective. The subsequent sections will consider the more general model, that of multiple-way interactions between the different vendors.

4. Interaction between Two Jobs

In this section, we consider the interaction of two jobs. A general modeling of interaction will be addressed in the next section.

4.1 Simple Model

Consider N jobs to be either done in-house or outsourced to a vendor. There will be either a fixed cost for in-house production of job i, c_i, or a fixed cost for the outsourcing job i when it is assigned to vendor k, d_{ik}. A transaction cost h_{ik} appears when vendor k is assigned job i. This expected cost relates to the ability of vendor k to do job i at the expected level and can be evaluated by the vendor performance matrix discussed earlier. z_{ij} models the cost due to the inter-dependence of two particular jobs under outsourcing consideration, i and j, $i \neq j$. There are five possible scenarios in assigning the two jobs, denoted by $S = \{1, 2, 3, 4, 5\}$, and described as follows:

1. Both jobs i and j are outsourced to the same vendor k;
2. Job i is outsourced to a vendor k and job j is produced in-house;
3. Job i is produced in-house and job j is outsourced to vendor k;
4. Both jobs i and j are produced in-house;
5. Both jobs i and j are outsourced, but to different vendors k and l ($k \neq l$)

Let r_{ij}^{S} $s \in S$ be the scenario specific coordination cost due to the inter-dependence between jobs i and j, for scenario s. Let $k = 0$ indicate in-house production, while $k = 1, 2, ..., K$ indicate outsourcing. The following are the other notations used in the model:

N = number of jobs to be performed;

S = $\{1, 2, 3, 4, 5\}$ are the possible scenarios in assigning jobs i and j to be outsourced or done in-house;

M = number of types of resources in the company;

c_i = fixed cost for producing job i in-house;

d_{ik} = fixed cost for outsourcing job i when it is assigned to vendor k ($k \neq 0$);

h_{ik} = transaction cost when job i is assigned to vendor k (for $k \neq 0$);

r_{ij}^{s} = cost due to the inter-dependence of job i and job j under the scenario s;

Q_m = maximum resource m available in the company (units);

a_{im} = amount of resource m required by job i(units);

x_{ik} = 1 if job i is assigned to vendor k, otherwise $x_{ik} = 0$,

z_{ij} = the coordination cost due to the specific assignment of jobs i and j.

Our formulation is given as follows:

$$\text{Minimize} \quad \sum_{i=1}^{N}\sum_{k=1}^{K} (c_{ik} + h_{ik})x_{ik} + \sum_{i=1}^{N}\sum_{k=1}^{K} d_{ik}x_{ik} + \sum_{i=1}^{N}\sum_{j>i}^{N} z_{ij} \tag{1}$$

subject to

$$\sum_{i=1}^{N} a_{imk}x_{i1} \le A_{mk} \qquad \text{for } m = 1, 2, \ldots, M;\ k = 1,2,..K \tag{2}$$

$$z_{ij} \ge r_{ij}^{1}\left[x_{ik} + x_{jk} - 1\right] \qquad \text{for } i<j,\ i, j = 1, 2, \ldots, N;\ k = 2,3, \ldots, K \tag{3}$$

$$z_{ij} \ge r_{ij}^{2}\left[x_{j1} + \sum_{k=1}^{K} x_{ik} - 1\right] \qquad \text{for } i<j,\ i, j = 1, 2, \ldots, N;\ \text{for } k= 1,2, \ldots, K \tag{4}$$

$$z_{ij} \ge r_{ij}^{3}\left[x_{i1} + \sum_{k=1}^{K} x_{jk} - 1\right] \qquad \text{for } i<j,\ i, j = 1, 2, \ldots, N;\ \text{for } k = 1,2, \ldots, K \tag{5}$$

$$z_{ij} \ge r_{ij}^{4}\left[x_{i1} + x_{j1} - 1\right] \qquad \text{for } i<j,\ i, j = 1, 2, \ldots, N;\ \text{for } k = 1, 2, \ldots, K \tag{6}$$

$$z_{ij} \ge r_{ij}^{5}\left[x_{ik} - x_{jk} - x_{j1}\right] \qquad \text{for } i, j = 1, 2, \ldots, N\ (i \neq j);\ \text{for } k = 1, 2, \ldots, K \tag{7}$$

$$x_{ik} \in \{0,1\} \qquad \text{for } i = 1, 2, \ldots, N;\ \text{for } k = 1,2, \ldots, K \tag{8}$$

$$\sum_{k=1}^{K} x_{ik} = 1 \qquad \text{for } i= 1, 2, \ldots, N \tag{9}$$

The objective of the formulation (1) is to minimize the total cost of assigning N jobs. Constraint (2) is capacity constraint of each resource such that the resources required for in-house production will not exceed the resource availability in the company. Constraints (3) through (A7) determine the cost due to inter-dependence when jobs i and j are assigned to a specific scenario s (1 to 5 respectively) described earlier. Note that only one of the constraints in (3) to (7) will be active at any one time. For example, if job i is outsourced to a vendor k

and job j is produced in-house, $\sum_{k=1}^{K} x_{ik} = 1$ and $x_{j1} = 1$ and hence only Constraint (4) is active with $z_{ij} \geq r_{ij}^2$. For the other constraints on z_{ij}, the right-hand-sides are all zero or negative under this particular combination of x_{ik} and x_{j0}. Constraint (8) constrains the decision variable to be binary (a job is either outsourced or produced in-house). Constraint (9) states that each job i will only be assigned to one production unit which is either in-house production or a vendor k.

4.1.1 Numerical Example 1

This example illustrates a simplified multiple vendor problem modeled on a spreadsheet using Solver to demonstrate that practical use of the model. Our primary focus using this example is to show how modeling this problem on a spreadsheet can aid managerial decision making. A second problem illustrates how the problem can be solved in general using the proposed formulation.

In the initial scenario in the first problem, called Model I, a company is considering outsourcing five IT related functions – education and training (Job 1) system development (Job 2), maintenance programming (Job 3), system integration (Job 4) and telecommunication (Job 5). There are three vendors for the company to choose from. The three vendors have different capabilities in doing the different functions or jobs. Initially we assume their capacity to be unlimited. Later we limit this capacity. They also charge different prices and have different transaction costs based on vendor selection criteria. Table 2 shows the fixed costs of in-house production and outsourcing (vendor prices).

Table 2: The production costs for in-house production and outsourcing ($ millions)

Jobs	1	2	3	4	5
In-house production	10	9.9	0.5	3.2	6.8
Vendor 1	5.5	9.6	0.9	3	5.5
Vendor 2	7	5	1	2.8	6.6
Vendor 3	15	14	2	3.9	6.3

As an example of transaction costs, the cost if Job 1 is assigned to Vendor 1 is shown in Table 3. As mentioned earlier the costs shown in the table are estimated by managers using

the vendor performance matrix based on historical experience. According to Table 3, the resulting expected transaction cost is 0.24 Million for Vendor 1 to do Job 1. This analysis has to be done for every vendor-job combination. Table 4 shows the expected transaction costs for the three different vendors doing the five different jobs.

Table 3: Expected transaction cost for Vendor 1 doing Job 1 ($ millions)

Performance (A)	Cost (B)	Probability (C)	Weighted Cost (D)
GOOD	0.01	0.25	0.0025
FAIR	0.25	0.55	0.1375
POOR	0.50	0.20	0.1000
Resultant expected transaction cost (Sum of Column D)			0.2400

For example if Job 2 is outsourced to Vendor 1, the managers have determined that there is additional $319,000 in transaction costs to be expected. This is in addition to the price quoted by the vendor and reflects the costs such as the additional negotiation costs during the contract that may be incurred compared to doing the job in-house. If the vendor performs poorly, the cost of any negotiations to ensure quality as well as negotiation over costs such as downtime and associate productivity losses may be included here. As mentioned earlier opportunism by the vendor may also be an issue. Further if Job 2 is outsourced to Vendor 2, the managers have determined that there is $446,000 in transaction costs to be expected. This is $127,000 more than that of Vendor 1. This additional cost may reflect the fact that Vendor 1 might have already done jobs for the company and the managers may feel that there is likely to be fewer problems in the relationship leading to lower transaction costs.

Table 4: Expected transaction costs for vendor-job combinations ($ millions)

Expected transaction costs	1	2	3	4	5
Vendor 1	0.240	0.319	0.0400	0.164	0.124
Vendor 2	0.303	0.446	0.0630	0.164	0.132
Vendor 3	0.107	0.104	0.0225	0.072	0.062

The costs for each pair are shown in Table 5 (Scenario 3 can be obtained by transposing the rows and columns in the table). If Job 1 is produced in-house and Job 2 is outsourced, the managers have determined that since Job 1 and Job 2 are inter-related, there is additional $200,000 in coordination costs to be expected. This is additional to the price quoted by the vendor and reflects the costs such as the additional communication costs incurred compared to doing both the jobs in-house, where communication and coordination between the jobs would be easier. Further if Job 1 is done in-house and Job 4 is outsourced, the managers have determined that there is additional $300,000 in coordination costs to be expected. This is $100,000 more than the combination of Jobs 1 and 2. This additional cost may reflect the fact that the relations ship between Jobs 1 and 4 may be more complicated than that between Jobs 1 and 2. Thus when one is outsourced and the other kept in-house, the coordination costs are relatively greater reflecting the difficulty in managing the in-house-outsourcing combination.

Note that the costs are not symmetric, i.e., the interdependence cost of doing Job *i* in-house and outsourcing Job *k* is not the same as doing Job *k* in-house and outsourcing Job *i*. Consider two jobs – one of $5 million and another of $1 million. The coordination costs between the two jobs is likely to different if we did the $5 million job in-house while outsourcing the $1 million job as opposed to the other way around.

Table 5: Costs due to interdependence of jobs when job *i* outsourced and job *j* done by in-house (Scenario 2 in $ millions)

Jobs	Outsource to one of the vendors				
In-house	1	2	3	4	5
1	0.00	0.20	0.20	0.30	0.10
2	0.50	0.00	0.50	0.30	0.20
3	0.20	0.10	0.00	0.10	0.12
4	0.40	0.30	0.20	0.00	0.30
5	0.30	0.20	0.25	0.40	0.00

Table 6 shows the resources required for each job. This relates the equation (2) which constrains the number of jobs that can be done in-house. For example, Job 1 requires labor worth $100 million, hardware worth $50 millions and expertise worth $20 million. As seen

from the table the company naturally cannot do all the jobs as they have limited resources of $200 millions for labor, $100 million for hardware and $50 millions for expertise. Therefore, the resources required for all the jobs done in-house have to be less or equal to the maximum resources available in the firm.

Table 6: Resource requirements and availability ($ millions)

Resources required	1	2	3	4	5	Available
Labor cost	100	150	50	150	180	200
Hardware cost	50	30	20	30	40	100
Expertise cost	20	25	10	30	20	50

Table 7 shows the minimum cost solution obtained using the Excel Solver, It is seen that that the firm should have Job 1 outsourced to Vendor 1 and Jobs 2, 3 and 4 outsourced to vendor 2. The model also suggests that the firm should keep job 5 in-house. The total cost of this plan would be $24.297 million.

Table 7: Optimal solution for Model I (assigned = {1}; not assigned = {0})

Jobs	1	2	3	4	5
In-house production	0	0	0	0	1
Vendor 1	1	0	0	0	0
Vendor 2	0	1	1	1	0
Vendor 3	0	0	0	0	0

4.2 Modelling What-If Managerial Considerations

4.2.1 Underutilization Cost

Note that the solution suggests that company do only Job 5 in-house. This might result in the company having much excess resources in the short term (assuming that it cannot be redeployed). Costs such as the salaries of existing personnel, and the amortization of equipment and facilities would often exist whether less jobs are done in-house or not. To better utilize the resources of the firm, the company would need to penalize unused resources.

This could be incorporated by including a cost for unused resources (equation 12 below). We assume that the company will incur a cost of b_{1m} per unit for the unused in-house resource m and y_{1m} represents the unused amount of resource m in units. Equation (1) would also be revised in order to add a underutilization penalty of $b_{1m} \times y_{1m}$. Also Equation 2 would change to

$$\sum_{i=1}^{N} a_{im1} x_{i1} + y_{1m} = A_{1m} \qquad \text{for } m = 1, 2, \ldots, M \qquad (12)$$

Table 8 shows the optimal assignment for Model II. As expected the model suggests more in-house production. Jobs 3 and 4 should be produced in-house compared to only Job 5 being produced in-house in Model I. The total cost of the revised plan is will $32.472 million. If the original plan (Model I) ignoring the underutilization cost was implemented, and the underutilization cost was real, then the actual cost would be $44.237 million (the sum of $24.237 million in the Model I and the underutilization costs of $19.94 million that would be incurred). This emphasizes the importance of properly identifying the various costs in the outsourcing decision. Table 9 compares the resources used in Models I and II. It is seen that the resources are better used in Model II.

The revised model with underutilization cost (Model II) actually reflects the costs of inflexibility in resources. If resource usage could be reduced or redeployed when less production is done in-house, then Model I provides the best solution. However if the resources cannot be reduced or redeployed adequately, then we have to include an underutilization cost and the cost of this inflexibility is the difference in the costs between Model I and Model II. In our example this cost of inflexibility is $8.175 million ($32.472 million - $24.297 million).

This type of analysis will help focus management attention on the cost of resource inflexibility within the organization and work toward improving this flexibility.

Table 8. The optimal job assignments for Model II with underutilization penalty (assigned = {1}; not assigned = {0})

Jobs	1	2	3	4	5
In-house production	0	0	1	1	0
Vendor 1	1	0	0	0	0
Vendor 2	0	1	0	0	0
Vendor 3	0	0	0	0	1

Table 9: Resources used Models I and II ($ millions)

Resources used	Model I	Model II	Resource Availability
Labor	180	200	200
Hardware	40	50	100
Expertise	20	40	50

4.2.2 Limiting the relative bargaining power of the vendors

One factor that would induce a limit on the number of jobs outsourced to the same vendor is the concern about the loss in our bargaining power and increase in their bargaining power when the same vendor becomes a major part of our business. Note that Model I, where vendors have unlimited capacity suggests that we outsource three out of the five jobs to the same vendor. In fact some vendors may offer better prices if multiple jobs are awarded to them. The model may then decide to assign more jobs to that vendor in order to save money. However we may not want to outsource a large percentage of our jobs to the same vendor. In the long term such a strategy may prove to be counterproductive as the company may lose bargaining power in future outsourcing contracts. As a result the company may suffer from the lack of power and control in managing its IT activities. Further, the high dependence and reliance on a particular vendor may then increase the risk in opportunism and operational problems. Thus, Lacity and Willcocks (1998) suggest that selective outsourcing could provide more flexibility as well as better control over the IS functions. Therefore, the company may

consider limiting the total number of outsourcing assignments to each vendor in order to prevent loss of control over its IT function.

Model III reflects this consideration. In this model the maximum job assignments for each vendor in Model I is restricted. V represents the maximum number of jobs that can be outsourced to any vendor. In our example $V = 2$. The results are shown in Table 10.

<u>Model III</u>

$$x_{ik} \leq V \qquad \text{for } i = 1, 2, \ldots, N;\ k = 2, 3, \ldots, K \qquad (13)$$

Table 10: Optimal job assignment for Model III (assigned = {1}; not assigned = {0})

Jobs	1	2	3	4	5
In-house production	0	0	1	1	0
Vendor 1	1	0	0	0	0
Vendor 2	0	1	0	0	0
Vendor 3	0	0	0	0	1

Compared to Model II (Table 8) each vendor will now be assigned to only one job, while in Model I three jobs were outsourced to Vendor 2. Model III also suggests keeping two job functions in house. The company will then have more in-house production than before which can better utilize the resources of the company. The total cost for Model III is $24.472 million which is slightly higher than the $24.297 million in Model I. The small difference in costs reflects the price the company is paying for maintaining its bargaining power in the long run.

Limiting the number of jobs assigned to each vendor also encourages competition in the market and also reduces the potential for opportunism. In fact, greater competition would bring in lower bids, better services and more satisfactory performance. This is true especially in the case where the number of possible vendors is limited as in our problem. For example suppose one of the vendors (i.e. Vendor 1) increases their prices such that it is now 50 % greater than that of in-house production. This is shown in Table 11 with the revised prices in bold. Tables 12 and 13 show the optimal assignments for Models I and III given the revised prices.

Table 11: Revised prices ($ millions) with Vendor 1 price increase

Jobs	1	2	3	4	5
In-house production	10	9.9	0.5	3.2	6.8
Vendor 1	15	15	1.5	4.8	12.2
Vendor 2	7	5	1	2.8	6.6
Vendor 3	15	14	2	3.9	6.3

Table 12: Optimal job assignment for Model I with price increase (assigned = {1}; not assigned = {0})

Jobs	1	2	3	4	5
In-house production	0	0	0	0	1
Vendor 1	0	0	0	0	0
Vendor 2	1	1	1	1	0
Vendor 3	0	0	0	0	0

Table 13: Optimal job assignment for Model III with price increase (assigned = {1}; not assigned = {0})

Jobs	1	2	3	4	5
In-house production	0	0	1	1	0
Vendor 1	0	0	0	0	0
Vendor 2	1	1	0	0	0
Vendor 3	0	0	0	0	1

Both models will try to avoid assigning jobs to Vendor 1 due to the expensive production costs for this vendor. Note that the solution to Model I (Table 12) having four jobs outsourced to Vendor 2 (even more than in Model I with the original prices, the solution to which is shown in Table 8). We would in fact be outsourcing 80% of our jobs to one vendor.

This however goes against the strategy in Model III which is to avoid loss of future bargaining power. Applegate and Montealegre (1991) and Cross (1995) also argue that single vendor could lead to a higher switching cost due to the higher risk in opportunism. In addition we would be increasing our operational risk because of our reliance on one vendor. In the worst case the company may temporarily shut-down due to the failure in the performance of the single vendor. Finally we are decreasing competition which may affect the ability of the other vendors to develop their offerings. This may hurt us in the long run because our ability to locate capable vendors in the future may be affected. On the other hand, to maintain the company's bargaining power and a competitive market, Model III with the increased prices (solution shown in Table 13) suggests that Jobs 1 and 2 be outsourced to Vendor 2 and Job 5 to Vendor 3. It also suggests that the company should do Jobs 3 and 4 in-house. The total costs in Table 13 are $26.071 million while the assignment in Table 12 will cost us $25.896 million. This small difference in cost again can be construed as the cost of maintaining future bargaining power and maintaining competition in the field.

Isolating transaction and coordination cost effects

From a strategic perspective, isolating transaction and coordination costs are useful. It allows analysis of aspects other than quoted prices, that is, the often hidden costs of outsourcing. In order to do this we assume that the cost for performing the function is identical regardless of whether it is done in-house or outsourced i.e., $c_{i1} = c_{ik}$, for all k. Table 14 shows such a situation. Thus the critical factors in the outsourcing decision would be the transaction and coordination costs for the job functions.

Table 14: identical function performance costs ($ millions)

Jobs	1	2	3	4	5
In-house production	10	9.9	0.5	3.2	6.8
Vendor 1	10	9.9	0.5	3.2	6.8
Vendor 2	10	9.9	0.5	3.2	6.8
Vendor 3	10	9.9	0.5	3.2	6.8

Table 15 shows the optimal assignments for Model I with the revised costs from Table 14. Note that the constraints stated in Table 6 also remain. The model recommends that the company do Job 2 in-house and outsource Jobs 1, 3, 4 and 5 to Vendor 3. The total cost is $32.441 million. Since the total direct production cost is the same regardless of the assignment (in millions, the sum of 10, 9.9, 0.5, 3.2 and 6.8, for a total of $30.4 million), the

difference between the direct cost and total cost (approximately $2 million) represents the transaction and coordination costs when holding direct production costs constant. This can be used to compare the vendors on aspects other direct production costs. For example Table 4 shows that Vendor 3 has lower transaction costs than the other vendors. However in Model I, Vendor 3 was not selected since it has higher quoted prices. But when prices are equalized, it is seen that Vendor 3 is preferred partly because of the transaction costs. Recall from Table 5 that the transaction costs were determined based on vendor selection criteria. From the vendor performance matrix, users can clearly identify which vendor has the least additional costs for governing and monitoring. These are indications of vendor quality and can lead to a qualitative analysis which might enhance the decision making in deciding whether to outsource to a certain vendor. For example, since Model I indicates that three jobs should be outsourced to Vendor 2 while Table 15 indicates that Vendor 3 is preferred from a transaction cost perspective, it might be worth while doing a sensitivity analysis on the performance possibilities of Vendor 2. In the worst case will outsourcing to Vendor 2 result in non performance? One could decide that the worst case performance of Vendor 2 is something that the company cannot afford and decide to offer the outsourcing contract to Vendor 3 instead. Further the lower coordination costs when out sourcing to Vendor 3 may also be a factor.

Assume that Job 2 has high interrelationship costs if outsourced with any of the other jobs. This indicates that if outsourced considerable effort will have to be expended in coordinating it with the jobs outsourced to other vendors. In order to avoid these costs the model suggests that Job 2 be kept in-house. In Model I, it appeared that since the in-house production costs for Job 2 was relatively high with respect to outsourcing options, outsourcing it might be a good option. But when the quoted costs are equalized, the coordination costs are more clearly seen. Like examining Vendor 2 from a transaction cost perspective it may be worthwhile examining Job 2 from an interrelationship cost perspective. In the worst case might the coordination cost between the company and the vendors prove to be more than what the company can afford if Job 2 is outsourced? If the answer is affirmative then perhaps the company to reexamine the results in Model I.

This type of analysis would support the development of situation-specific supplier selection strategies suggested by Soukup (1987). If the solution in Table 15 is not desirable from a bargaining power aspect since three jobs are outsourced to the same vendor, one could apply the restrictions discussed earlier to have the outsourced jobs distributed to different vendors.

Table 15: The optimal solution Model I with identical function performance costs ($ millions) (assigned = {1}; not assigned = {0})

Jobs	1	2	3	4	5
In-house production	0	1	0	0	0
Vendor 1	0	0	0	0	0
Vendor 2	0	0	0	0	0
Vendor 3	1	0	1	1	1

5. Multiple-Way Interaction of Jobs

Consider N jobs to be either done in-house or outsourced to a vendor (with up to K vendors available). Let:

M = number of types of resources in the company

c_{ik} = fixed cost for outsourcing job i when it is assigned to vendor k (where $k = 1$ implies in-house production)

h_{ik} = transaction cost when job i is assigned to vendor k (for $k \neq 1$)

q_{ij} = coordination information flow from project i to project j.

d_{kl} = unit cost of managing coordination information flow from vendor k to vendor l

A_{mk} = resource availability of type m available in company or at vendor k (units)

a_{imk} = amount of resource m required by job i in company or at vendor k (units)

x_{ik} = 1 if job i is assigned to vendor k, otherwise $x_{ik} = 0$

The model is as follows:

Minimize $$\sum_{i=1}^{N}\sum_{k=1}^{K}(c_{ik}+h_{ik})x_{ik} + \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{K}\sum_{l=1}^{K} q_{ij}d_{kl}x_{ik}x_{jl} \quad (10)$$

Subject to

$$\sum_{i=1}^{N} a_{imk}x_{ik} \le A_{mk} \qquad k = 1,2,..K;\ m = 1, 2,..M \quad (11)$$

$$\sum_{k=1}^{K} x_{ij} = 1 \qquad i = 1,2,..N \quad (12)$$

$$x_{ij} \in \{0,1\} \quad \forall i, j \tag{13}$$

The objective of the formulation (equation 10) is to minimize the total cost of assigning N jobs The first term of (10) assigns a fixed contract cost and a transaction cost to each job assigned. The second term of (10) models the coordination cost. Suppose project i is outsourced to vendor k and project j is outsourced to vendor l. Then the cost of the coordination will be $q_{ij} \times d_{kl}$. It is possible that q_{ij} and q_{ji} may be different; it is also possible that d_{kl} and d_{lk} may be different. The value assigned to d_{kl} can take into account many types of communication costs as well as synergies and inefficiencies that exist between the pair of vendors. Thus, this model accommodates many practical considerations. Equation (11) constrains the sum of the jobs assigned in-house or to a vendor to less than that availability of the different resources required to do each job. Equation (12) ensures that each job is assigned.

5.1 Equivalent Linear Model

This is a modified version of the Koopmans-Beckmann Problem (KBP) where the first constraint regarding capacity is a modified version of the assignment constraint (see Koopmans and Beckmann, 1957). KBP is a special case of the Quadratic Assignment Problem (QAP) where the product $q_{ij} \times d_{kl}$ appears in a more general form represented by a single variable f_{ijkl}. The problem is quadratic due to the product term $x_{ik} \times x_{jl}$ in the objective function. It is hard to solve due to the binary variables and the quadratic objective function. In fact the QAP is NP-hard (Garey and Johnson, 1976) and non approximable (Sahni and Gonzalez, 1976)

For situations where there are 10 or less projects projects to outsource and not more than 5 vendors, it is possible to solve the problem within a matter of seconds using Mixed Integer Quadratic Constrained Problem (MIQCP) solvers available today. Larger problems (12 projects and 12 vendors) can be solved by a linearization of the problem based on Kaufman and Broeckx (1978). This is described below and is applied to the proposed problem. Let w_{ik} = the effective coordination cost of assigning project i to vendor k (for all i, k). w_{ik} is constrained as follows using a large number M (big M):

$$Mx_{ik} + \sum_{j=1}^{N}\sum_{l=1}^{K} q_{ij} d_{kl} x_{jl} - w_{ik} \le M \qquad \forall i, k \tag{14}$$

This constraint will force w_{ik} to equal $\sum_{j=1}^{N}\sum_{l=1}^{K} q_{ij} d_{kl} x_{jl}$ whenever x_{ik} = 1 and will let w_{ik} equal zero otherwise. In effect, w_{ik} is the coordination cost of assigning project i to vendor k, whether that assignment is actually made or not. Logically, the smallest value for M is $\sum_{j=1}^{N}\sum_{l=1}^{K} q_{ij} d_{kl}$ for all i, k. The linearized problem thus becomes:

$$\text{Minimize} \quad \sum_{i=1}^{N}\sum_{k=1}^{K} (c_{ik} x_{ik} + w_{ik}) \tag{15}$$

Subject to

$$\sum_{i=1}^{N} a_{imk} x_{ik} \le A_{mk} \quad \forall k, m \tag{16}$$

$$\sum_{k=1}^{K} x_{ij} = 1 \quad \forall i \tag{17}$$

$$\left[\sum_{j=1}^{N}\sum_{l=1}^{K} q_{ij} d_{kl}\right] x_{ik} + \sum_{j=1}^{N}\sum_{l=1}^{K} q_{ij} d_{kl} x_{jl} - w_{ik} \le \left[\sum_{j=1}^{N}\sum_{l=1}^{K} q_{ij} d_{kl}\right] \quad \forall i, k \tag{18}$$

$$w_{ik} \ge 0 \quad \forall i, k \tag{19}$$

$$x_{ij} \in \{0,1\} \quad \forall i, j \tag{20}$$

The linearity of the above problem makes it possible to solve it as a Mixed Integer Linear Programming (MILP) problem. The number of variables has doubled, though, due to the introduction of w_{ik}. Furthermore, there are $N \times K$ number of additional constraints (excluding non negativity constraints for w_{ik}). Still, for small problems, the linearization results in a reduction in solution time. For large problems, with 20 projects and 20 vendors, even this method can take too much time to be practicable. Kaufman and Broeckx (1978) describe another method using Benders' decomposition which is beyond the scope of this paper.

For larger problems many meta-heuristics have also been proposed. Anstreicher (2003) gives a summary of recent developments in solution procedures. Drezner (2003) describes a genetic algorithm. Cheng and Patterson (2003) describe simulated annealing and tabu search methods. Misevicius (2005) describes another tabu search method. Middendorf et al. (2002) describe an ant colony algorithm. The reader is referred to these for further information.

5.2 Numerical Example 2

The second example focuses on the mathematical programming solution to the outsourcing problem considering multiple-way interaction among jobs. Consider a 10 project,

4 vendor problem. The data for the problem is given in Figure 1 below. V1 indicates in-house production. The c_{ik} data gives the cost of assigning the job (project) i to vendor j or doing it in-house. For example, project 1 (P1) would cost (in thousands), $650 (fixed) to be done in-house but only $490 if outsourced to vendor 2 (V2). For simplicity, the interaction cost of the job has been ignored. The q_{ij} data gives the cost of coordination between any pair of projects i and j while the d_{kl} data gives the cost of coordinating vendors k and l for every $1000 of interaction between projects. So the greater the interaction between projects, greater would be the cost of coordination between the vendors to whom this job is outsourced. For example consider assigning project 1 to vendor 2, project 2 to vendor 3 and project 3 to vendor 4. We can ignore the other assignments for now. Table 16 gives the various costs for this scenario. It is seen for instance that because P1 is outsourced to V2 and P2 is outsourced to V3, there will be a $30 ($15 each way) cost of coordination between the two outsourced projects. This is because there is a $5 between vendor coordination cost for every $1 of coordination cost between projects (assigned to these two vendors), due to the interaction between the two projects. Since $3 worth of project coordination is required each way, the coordination cost due to this assignment is $15 each way. The total cost consists of $1568 of fixed contracting cost and $65 of coordination cost because of the particular assignment of projects to vendors. Note that each job i requires a certain amount of resource a_i (we consider only one resource for simplicity) and each vendor has a limited amount of this resource available (A_k).

C_{ik} data					
	V1	V2	V3	V4	V5
P1	650	490	548	576	548
P2	548	487	500	478	600
P3	490	580	487	578	608
P4	548	564	548	611	642
P5	690	690	672	548	580
P6	390	432	387	411	350
P7	700	690	548	548	548
P8	548	548	722	722	612
P9	890	890	560	722	692
P10	890	890	722	698	665

q_{ij} data										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1	0	3	1	3	3	4	4	6	3	3
P2	3	0	3	8	3	2	1	4	2	5
P3	6	3	0	3	7	4	4	5	3	2
P4	3	3	3	0	3	3	3	6	5	7
P5	3	1	3	3	0	3	3	6	6	3
P6	3	3	6	6	3	0	3	4	6	3
P7	5	3	6	6	3	3	0	3	3	1
P8	3	3	3	8	3	3	3	0	2	3
P9	3	5	3	3	3	8	3	3	0	3
P10	3	1	4	3	3	6	3	7	4	0

a_i data	
P1	12
P2	8
P3	6
P4	7
P5	11
P6	3
P7	5
P8	4
P9	9
P10	11

d_{kl} data					
	V1	V2	V3	V4	V5
V1	1	3	8	6	7
V2	3	1	5	5	2
V3	8	5	1	5	5
V4	6	5	5	1	4
V5	7	2	5	4	1

A_k data				
V1	V2	V3	V4	V5
21	15	12	23	22

Figure 1. Data for a 10 project, 4 vendor problem

Table 16: Total cost (in $ thousands) for hypothetical outsourcing scenario

Project	Outsourced to	Contract Cost ($)	q_{ij} ($) (based on Figure 1)	d_{kl} ($)	$q_{ij} \times d_{kl}$
P1	V2	490	P_1 and P_2 = 3	V_2 and V_3 = 5	15
			P_1 and P_3 = 1	V_2 and V_4 = 5	5
P2	V3	500	P_2 and P_1 = 3	V_3 and V_2 = 5	15
			P_2 and P_3 = 3	V_3 and V_4 = 5	15
P3	V4	578	P_3 and P_1 = 6	V_4 and V_2 = 5	30
			P_3 and P_2 = 3	V_4 and V_3 = 5	15
Total		1568			95

Optimal x_{ik}					
	V1	V2	V3	V4	V5
P1	0	0	0	1	0
P2	0	1	0	0	0
P3	1	0	0	0	0
P4	0	1	0	0	0
P5	0	0	0	1	0
P6	0	0	0	0	1
P7	0	0	0	0	1
P8	1	0	0	0	0
P9	0	0	1	0	0
P10	0	0	0	0	1

Optimal w_{ik}					
	V1	V2	V3	V4	V5
P1	0	0	0	134	0
P2	0	85	0	0	0
P3	195	0	0	0	0
P4	0	111	0	0	0
P5	0	0	0	143	0
P6	0	0	0	0	148
P7	0	0	0	0	132
P8	151	0	0	0	0
P9	0	0	188	0	0
P10	0	0	0	0	138

Figure 2. Solution for the 10 project, 4 vendor problem

The problem was solved as a linearized MILP problem using w_{ik} variables suggested earlier. The optimal solution shown in Figure 2. The optimal solution is to do Project 1 and Project 8 in-house while outsourcing the other projects. The cost of doing the outsourced projects is $4138 (fixed outsourcing contract costs) plus $1425 in coordination costs. The cost of doing the two in-house projects is $1198. So the optimized total cost of completing all the projects is $6761.

6. Conclusion

This paper addressed an important problem in IT management, namely the outsourcing of IT functions. As evident from the literature, IT outsourcing is becoming more common and global. Thus it is important that more research be done on the process. Also from the literature, it is clear that outsourcing involves multiple considerations. To address these issues, we developed a multiple vendor model that considers not only direct production costs (such as labor, facilities, and expertise for in-house jobs; and vendor quote for outsourced jobs) but also some of the hidden costs of outsourcing such as the transaction (bargaining and opportunism) and coordination (between outsourced and in-house jobs) costs. Mixed Integer Programming (MIP) using a spreadsheet proved to be a practical and useful tool for solving the problem optimally. In our initial model formulation, we assumed interdependence only between any pair of jobs. In practice, the interdependence may involve more than two jobs which may present a multi-dimensional relationship rather than pair-wise relationship. We model this using the QAP and present a linearized version of the problem.

We used a numerical example implemented on a spreadsheet to illustrate the model and also to develop managerial insights into IT outsourcing. Since ours is an optimization model it is able to select the best assignment of jobs to vendors. This is done with multiple considerations making the model applicable in practical situations. In addition, it is implemented on a spreadsheet, therefore, what-if analysis becomes more feasible. For example if the problem parameters in the objective function or constraints changed, it is possible to reoptimize it quickly with the changes. In addition if the situation itself changed such that constraints or vendors had to be added, this would be feasible too. Thus our model allows for scenario analysis, which is important given the dynamic nature of business today. In addition this scenario analysis would give the decision maker additional insight into the outsourcing problem, and thus ultimately lead to better decisions. From a managerial perspective, our paper highlights the importance of using optimization models since it can save the company money. IT is a big ticket item for many companies today given the pervasiveness and complexity of such systems within organizations. Thus even improving the

efficiency in outsourcing by a few percent can impact the bottom line significantly. However the outsourcing decision in made under various constraints. Thus it is important to use a constrained optimization model. Further it is important that the decision not be made as a black box, since employees are more likely to accept decisions that they understand and perceive as fair. Black box type decision models often do not satisfy the transparency and fairness criteria. Since we implemented our model using spreadsheets, a ubiquitous technology in business today, our model is an excellent tool to communicate and explain decisions. So it should be more acceptable to employees affected by the decision. Thus our paper should be useful to academicians researching the topic of IT outsourcing and to practitioners. Our model may also be extended to outsourcing in general.

Our model considered only the minimization of costs. In practice of course the organizations interested in outsourcing IT functions may be interested in other objectives such as quality, flexibility and strategic fit. Further our model used deterministic inputs. Thus future work could involve multiple criteria constrained decision making models to address multiple objectives and perhaps the use of simulation to examine the effect of uncertainty in the values of problem parameters.

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